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by

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November 1965

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ABERDEEN PROVING GROUND, MARYLAND

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# OVERPRESSURES AND DURATIONS OF SHOCK WAVES EMERGING FROM OPEN-ENDED SHOCK TUBES


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MEMORANDUM REPORT NO. 1724

BRBertrand/WTMatthews/blw
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# OVERPRESSURES AND DURATIONS OF SHOCK WAVES EMERGING FROM OPEN-ENDED SHOCK TUBES

## ABSTRACT

The field wave overpressures and durations resulting from shock waves emerging from open-ended shock tubes have been measured. An equation has been developed from the measured data that relates the field overpressures (below 0.1 psi) resulting from a given shock tube pressure, to the tube diameter and distance from the tube exit. An equation has also been developed from the same data that relates the duration of the field wave (below 0.1 psi) to the exit areas of the tubes for a given shock tube pressure. Predictions of field overpressure and duration have been made for an eight foot diameter shock tube firing a 27 psi shock wave.

TABLE OF CONTENTS

## LIST OF SYMBOLS

| | |
|---|---|
| $A_E$ | Excess attenuation due to atmospheric and ground effects, decibels |
| D | Shock tube diameter, inches |
| DI($\alpha$) | Directivity index, a function of angle $\alpha$, decibels |
| P | Pressure, pounds per square inch |
| PWL | Power level, decibels (reference power = $10^{-12}$ watts) |
| R | Distance from shock tube exit, feet |
| $SPL_R$ | Sound pressure level, decibels, (re: 170.8 db = 1.0 psi) at distance R |
| t | Time, milliseconds |
| $\alpha$ | Angle from the end of a shock tube between the tube axis and a radial |

Subscripts:

| | |
|---|---|
| 1, 2 | Refer to any two different values of distance, pressure, tube diameter or time. |

## I. INTRODUCTION

There has been active interest recently in the construction of large diameter shock tubes. One problem with a large diameter tube is that it usually has a dangerous open end. The shock wave emerges from the end of the tube and expands into the region surrounding the exit. The wave diminishes in pressure as it travels further from the tube. Part of the region into which the wave expands could be considered a potential danger area in which damage or injury could occur. Danger for particular objects within the area could be determined on the basis of field overpressures and wave durations. Several variables -- characteristic of the object, or target -- contribute to the determination. Among these variables are target size and shape, construction method and materials, and orientation with respect to the wave. If information on the overpressure and wave duration is available, it can be used with the known characteristics of targets to determine danger limits.

This report describes an effort to predict the field wave overpressure and duration for large shock tubes. The prediction method is based on empirical relations developed from measurements obtained with smaller tubes. These measurements were field wave overpressure and duration at various distances and angles from the exits of shock tubes with known diameters and shock pressures. In addition to the main line of investigation, the data were used to determine if the tube exits could be related to equivalent sound power sources for constant shock tube pressure.

## II. DESCRIPTION OF SHOCK TUBES

Four shock tubes at the Ballistic Research Laboratories (BRL) Shock Tube Facility were used. The tubes terminate over a flat grass-covered field. Figure I (Appendix) shows their general dimensions. Three of them are driven by cold gases and the fourth is driven by detonation.

The largest cold gas-driven tube has an inside diameter of 22 3/16 inches, an outside diameter of 24 inches and its open end is 275 feet from the diaphragm. The compression chamber used with this tube during these

tests was 55 feet long. The centerline of the tube is 5 feet above ground surface. This tube can produce up to 28 psi at the open end with an air driver.

Two smaller tubes were used. The larger of these has a 4 1/2-inch inside diameter and a 5-inch outside diameter. Length of the compression chamber varies from 4 1/2 to 16 feet. The expansion section is 16 feet long. The tube was mounted with its centerline 20 inches above the ground surface. With an air driver it can develop 30 psi; with helium it can develop 45 psi. The smallest tube used has a 1 7/8-inch inside diameter and a 2-inch outside diameter. Its compression chamber is 3 1/2 feet long and the expansion section is 9 feet long. The tube centerline was mounted 8 inches above the ground surface. This tube can produce 28 psi shocks.

The fourth is a large high pressure tube. The inside diameter of its 27 1/2-foot compression chamber is 8 inches. It is filled with a mixture of hydrogen and oxygen. A detonation wave is initiated in the mixture at the end of the chamber and travels to the diaphragm, where it drives a strong shock into the air contained in the first expansion section. This section is 8 1/4 inches inside diameter and 27 feet long. At its end, a conical transition increases the inside tube diameter to 22 inches. After 55 feet, a 17-inch wide plate flattens part of its circumference reducing the cross-sectional area to 328 square inches for the next 55 feet where the tube finally terminates. The end of the tube has a flat flange of 36 x 36 inches surrounding its exit. Shock waves up to 150 psi can be obtained at the end of this tube. The centerline of the tube is 30 inches above a concrete surface which is 14 feet wide and extends 60 feet beyond the end of the tube. The concrete surface is elevated about 4 feet above the field level. Because of the presence of this flange and the 4-foot drop-off to field level, we believe that the data obtained with this tube cannot be directly related to the data obtained with the other tubes which were not flanged. The flange changes the effective size of the exit as a power source by slowing the rate of decrease of the emerging shock pressure.

## III. MEASUREMENT PROCEDURE AND RELATED EQUIPMENT

The field at the end of each tube was laid out in radials. The line on the ground parallel to the tube centerline was called the $0^\circ$ radial, and the other radials were $25^\circ$, $45^\circ$, $65^\circ$, and $90^\circ$ in the plane of the field. Field overpressures and durations were measured along these radials. In addition to these measurements the shock tube pressure and wave duration were also obtained.

In order to relate the field wave overpressure and duration to the shock tube pressure and dimensions, the following data were recorded:

1. Ambient temperature and atmospheric pressure.
2. Wind velocity.
3. Distance along a radial from the tube end.
4. Field wave overpressure and duration along a radial.
5. Shock wave speed just prior to emergence from the tube.
6. Shock tube pressure vs time.

All shots were fired during periods of fairly constant weather conditions. Winds were light. The distances involved were considered too small for focussing effects of atmospheric origin.

Usually maximum field overpressures were measured with General Radio (GR) Sound Level Meters in conjunction with GR Impact Noise Analyzers. These instruments were calibrated with a GR Sound Level Calibrator driven by the GR Transistor Oscillator at 400 cps and 2.0 volts as recommended by the manufacturer. These instruments recorded the maximum field overpressure in decibels, with 170.8 decibels being equal to 1.0 psi.

In addition to measuring maximum field overpressures with the GR instruments we occasionally recorded field-wave pressure vs time with either an Atlantic Research pencil gage, a Consolidated Electrodynamic Corporation pressure gage or a Breul and Kjaer microphone. Outputs were recorded on oscilloscopes. Because of the long extension cords or generators required to power the oscilloscopes, they proved inconvenient.

Consequently, these instruments were used only for periodic checks of the field overpressure vs time histories from the various shock tubes. Also, since four of the GR instruments were available, we were able to economize our efforts by getting four pressure measurements at four different locations from each shock wave produced.

For the 22 3/16-inch tube (air-driven) and the high pressure shock tube (detonation-driven), the field was instrumented with the GR instruments at various distances along radials that made angles of $0^{\circ}$, $25^{\circ}$, $45^{\circ}$, $65^{\circ}$ and $90^{\circ}$ from the open end of the tubes. This arrangement enabled us to obtain lines of equal pressure vs distance from the end of each tube. The 4 1/2-inch tubes' field wave was measured along the $0^{\circ}$ and the $25^{\circ}$ radials and the 1 7/8-inch tube only along the $0^{\circ}$ radial. We can see no reason for tubes of similar open-end cross section (the air-driven tubes) having different directivity factors; for that reason the smaller tubes' field waves were not measured along other radials.

The shock wave overpressure in the tube was calculated using the shock wave speed and ambient tube temperature in the shock equation. In addition, the shock overpressure was measured with piezoelectric gages whose outputs, displayed on oscilloscopes, also gave the wave duration in the tube.

## IV. RESULTS

Figures 2 through 11 (See Appendix) show maximum field overpressures obtained with the GR instruments at various distances and angles from the 22 3/16-inch and the high pressure tubes. The variation in the field overpressure is shown as a function of shock tube overpressure.

Figure 12 shows the maximum field overpressures obtained on the $0^{\circ}$ radial of the 4 1/2-inch tube. Figure 13 shows results along the $25^{\circ}$ radial of the 4 1/2-inch tube for a range of shock pressures from 16.5 to 18.5 psi. Figure 14 shows the results of the measurements made along the $0^{\circ}$ radial of the 1 7/8-inch tube.

The data presented in Figures 2 through 11 are replotted on maps of the area beyond the end of the tubes as lines of equal field overpressure or pressure contours; this type of plot gives the general shape of the pressure field and shows how direction-sensitive the pressure field is. Figures 15 through 20 show the maps obtained in this manner. We believe that the maps for the high pressure tube are not typical of the usual open-ended tube because of the presence of the large flange on that tube and the elevation of its supporting surface above the field level.

If the data presented in Figures 2 and 12 are replotted for fixed distances on the $0^{\circ}$ radial, more simple plots are obtained. These are shown in Figures 21 and 22.

Figures 23 and 24 show typical field overpressure vs time records.

Figure 25 is a graph of absolute shock tube pressure ratios (atmospheres) vs distances in diameters along the $0^{\circ}$ radials of the four tubes used at which 0.01, 0.05 and 0.1 psi field overpressures were obtained.

The data from the 1 7/8-, 4 1/2- and 22 3/16-inch shock tubes agree quite well, but the high pressure tube data deviate for reasons discussed earlier (Section III).

## V. DISCUSSION OF RESULTS

Equations for predicting the overpressures (below 0.1 psi) and durations of field waves from large shock tubes can be derived from the measured data.

The field overpressure vs. distance plots on the $0^{\circ}$ radial Figures 2, 12, and 14 have essentially the same slopes for pressures below 0.1 psi. The relation between pressure and distance from the tube exits is approximately:

$$\frac{P_2}{P_1} = \left(\frac{R_2}{R_1}\right)^{-1.12} \qquad (1)$$

This relation means that the waves from all the tubes are attenuated in the same manner.

The severe drop-off in pressure beyond 40 feet from the 1 7/8-inch tube (Figure 14) is caused by its proximity to the ground (8 inches) and by its short wave length. We know that higher frequency waves attenuate more rapidly than low frequency waves[1*].

Also using Figures 2, 12, and 14 we can determine the ratio of the distance along the 0° radial at which the same field overpressure is obtained from two different diameter shock tubes firing the same shock pressure. The ratio is approximately equal to the ratio of the two tube diameters:

$$\left(\frac{R_2}{R_1}\right)_{\text{const P.}} = \frac{D_2}{D_1} \quad . \tag{2}$$

This equation can be used to predict distances from larger tubes at which the same pressure will be obtained.

From Figures 23 and 24 we see that the ratio of field wave durations from two different diameter shock tubes firing the same shock pressure is approximately the ratio of the tube diameters to the 0.6 power:

$$\frac{t_2}{t_1} = \left(\frac{D_2}{D_1}\right)^{0.6} \quad . \tag{3}$$

This equation enables us to predict durations for larger tubes.

The duration of the field waves increases slightly with increasing shock tube pressures for any given tube, but no rule can be suggested from the present data. To give some idea of the increase in duration a field wave of 7 milliseconds results from a 35 psi wave in the high pressure tube, and a field wave of 11 milliseconds results from a 150 psi wave in the same tube. Both of these values were obtained at 200 feet on the 0° radial.

Some field wave durations were also obtained on the 90° radial. They were about 2/3 the duration on the 0° radial.

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* *Superscript numbers denote references which may be found on page 20.*

Several shots fired from the same tube but with longer compression chambers showed the same results as those obtained with the shorter chambers. Apparently chamber length is not important, provided that it is long enough to produce a flat shock at the exit.

The measurements obtained can also be used to find if we can relate various tube diameters to sound power sources.

For sound attenuation with distance, the following equation is frequently used:

$$PWL = SPL_R + 20 \log R + DI(\alpha) - 10.5 \text{ db} - A_E \qquad (4)$$

where

| | |
|---|---|
| PWL | Source power level in decibels |
| R | Distance from sound source in feet |
| $SPL_R$ | Sound pressure level at distance R(re: 170.8 db = 1.0 psi) |
| $DI(\alpha)$ | Directivity index (a function of angle), in decibels |
| $A_E$ | Excess attenuation due to atmospheric and ground effects, in decibels. |

If the shock tube exit is considered a sound power source and we measure the distance R on the $0^{\circ}$ radial ($\alpha = 0$), further assuming for given tube-exit geometry that $DI(\alpha)$ is constant and that the same atmospheric conditions exist ($A_E$ = constant), then the Equation (4) can be written for any shock tube,

$$PWL = SPL_R + 20 \log R + \text{constant.}$$

If we assume the same strength shock emerging from each of two different diameter shock tubes and measure the distance from each of the two tubes to where the same field overpressure exists (i.e., where

$SPL_{R_1} = SPL_{R_2}$), a relationship between the relative power levels of the two tubes may be found:

$$PWL(db) = PWL_2 - PWL_1 = 20 \log R_2 - 20 \log R_1 . \tag{5}$$

The power ratio corresponding to PWL(db) can be found from tables in acoustic measurement books such as Reference 2.

The following table uses the curves of field overpressure vs. distance along the $0^o$ radial (Figures 2, 12, and 14), with Equation (5) to check the relationship of power ratio to tube area ratio:

TABLE I

| Shock-Tube Pressure (psi) | Tube Diameter (ins) | Field Pressure (psi) | Distance R (ft) | 20 log R | ΔPWL,db | Power Ratio | Shock-Tube Area Ratio |
|---|---|---|---|---|---|---|---|
| 27 | 1 7/8 | 0.06 | 15 | 23.5 | 7.85 | 6.08 | 5.75 |
| 27 | 4 1/2 | 0.06 | 37 | 31.35 | 13.85 | 24.3 | 24.3 |
| | 22 3/16 | 0.06 | 180 | 45.2 | | | |
| 27 | 4 1/2 | 0.01 | 190 | 45.6 | 12.1 | 16.22 | 24.3 |
| 27 | 22 3/16 | 0.01 | 770 | 57.7 | | | |
| 18 | 4 1/2 | 0.0078 | 115 | 41.2 | 14.5 | 28.2 | 24.3 |
| 18 | 22 3/16 | 0.0078 | 610 | 55.7 | | | |
| 18 | 4 1/2 | 0.0038 | 210 | 46.5 | 14.6 | 28.8 | 24.3 |
| 18 | 22 3/16 | 0.0038 | 1140 | 61.1 | | | |
| 9.5 | 4 1/2 | 0.0029 | 91 | 39.2 | 15.8 | 38 | 24.3 |
| 9.5 | 22 3/16 | 0.0029 | 560 | 55.0 | | | |

In the last two columns of Table I we see that there is only general agreement between power ratio and area ratio. Complicated wave interactions occur at the shock tube exit as the shock wave emerges. The shock wave expands from the exit in three dimensions and a circular rarefaction wave starts in towards the tube axis from the perimeter of the exit. For subsonic-flow shock waves, this rarefraction wave also propagates upstream into the shock tube accelerating the flow behind the shock front but rapidly lowering the pressure. As the rarefraction wave travels further, it tends to become weaker even though its front still travels at a constant speed. For a small diameter tube the rarefraction wave reaches the axis and lowers the pressure rapidly and decisively. In a larger tube the wave has a longer time in which to weaken before reaching the axis; consequently its pressure-lowering effect is felt there more gradually. We believe then that the ratio of the power levels of two different diameter tubes is not simply the ratio of the tube's exit areas, but is unbalanced in favor of the larger tube by the exit rarefraction wave effects.

Experimental difficulties encountered were the lack of precisely the same shock tube exit pressure for all tubes and the possible instrument error ( $\pm$ 1 decibel). Perhaps more serious was the effect of atmospheric conditions even though the tests were conducted on days that seemed similar according to weather data obtained.

## VI. TYPICAL PREDICTIONS FOR AN 8-FOOT DIAMETER SHOCK TUBE

To predict the distance at which a 0.01 psi field wave would be found on the $0^\circ$ radial of an 8-foot diameter shock tube firing a 27-psi shock wave, we use the following method.

From Figure 2 we find that 0.01 psi occurs at a distance of 760 feet from the 22 3/16-inch diameter shock tube on the $0^\circ$ radial. Using Equation (2), we find the distance at which the same value would be obtained for the 8-foot tube, (96 inches)

$$R_{96''} = \frac{(96'')(760')}{22\ 3/16''} = 3280 \text{ feet.}$$

From Equation (3) and Figure 24A, the field wave duration for the 8-foot tube would be

$$t_{96''} = \left(\frac{96''}{22\ 3/16''}\right)^{0.6} (7 \text{ milliseconds}) = 16.8 \text{ milliseconds.}$$

The distance on the $90^{\circ}$ radial at which 0.01 psi is obtained would be found in the same manner. Using Figure 6 we find that 0.01 psi is obtained at 250 feet on the $90^{\circ}$ radial for a 27 psi wave from the 22 3/16-inch tube. So for the 8-foot tube,

$$R_{96''} = \left(\frac{96''}{22\ 3/16''}\right)(250') = 1080 \text{ feet, } 90^{\circ} \text{ radial.}$$

From the discussion of duration we know that the duration on the $90^{\circ}$ radial is about 2/3 the duration on the $0^{\circ}$ radial, or $(2/3)(16.8) =$ 11.2 milliseconds.

## VII. CONCLUSIONS

Equations have been developed from field overpressure measurements of small tube-field waves that allow the prediction of field overpressure (below 0.1 psi) for larger tubes. The limits of a danger area can be predicted in the same manner if a maximum safe field overpressure is specified. The ratio of the distances from two different diameter shock tubes at which the same field overpressure will be obtained is the ratio of the tube diameters. The general shape of the lines of equal field overpressure have been found for two shock tubes having different exit configurations.

The duration of the field wave has also been found to be a function of the tube diameter and to some extent of the shock tube pressure. If we know the duration of the field wave for a given size shock tube and shock tube pressure, we can use the developed equations to find the duration of a field wave from a larger tube with the same shock pressure.

We have also found that the duration of the field wave on the $90^{\circ}$ radial is about 2/3 of the on-axis duration for the same shock tube pressure. The duration of the field wave does not depend on the compression chamber length if the chamber is long enough to produce a flat shock wave.

An attempt to relate open-ended shock tubes of different diameters to equivalent sound power sources resulted in only general agreement. The power ratio of two different diameter shock tubes firing the same shock pressures approximates the ratio of the exit areas of the two shock tubes.

BRIAN P. BERTRAND WILLIAM T. MATTHEWS

## REFERENCES

1. Beranek, L. L., editor. Noise Reduction. New York: McGraw-Hill, 1960.

2. Peterson, Arnold P. G. and Gross, Ervin E. Jr. Handbook of Noise Measurement (Fifth Edition). West Concord, Massachusetts: General Radio Company, 1963.

APPENDIX

FIGURES

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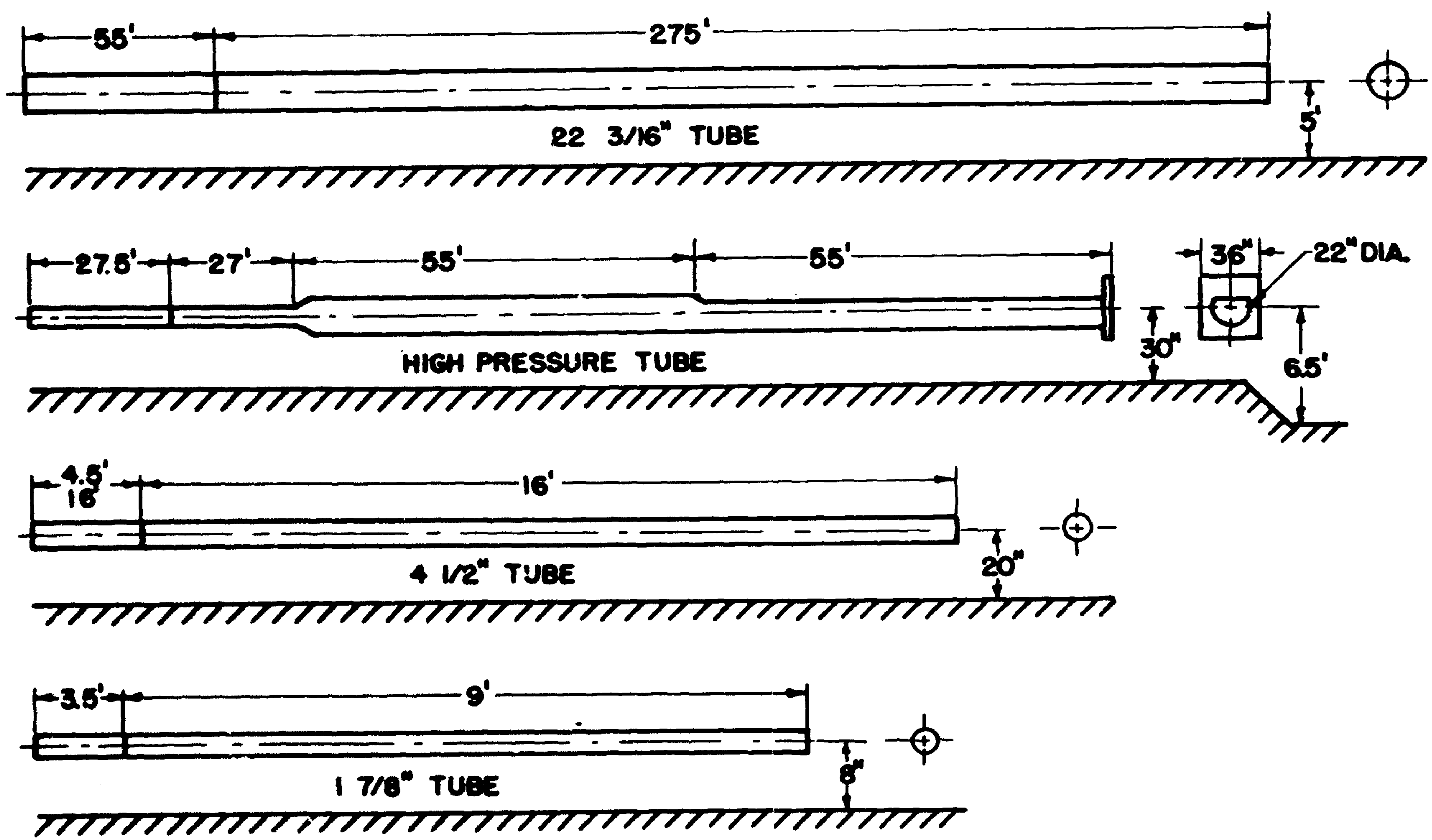



FIG. 1 SHOCK TUBES USED FOR OBTAINING FIELD OVERPRESSURE DATA

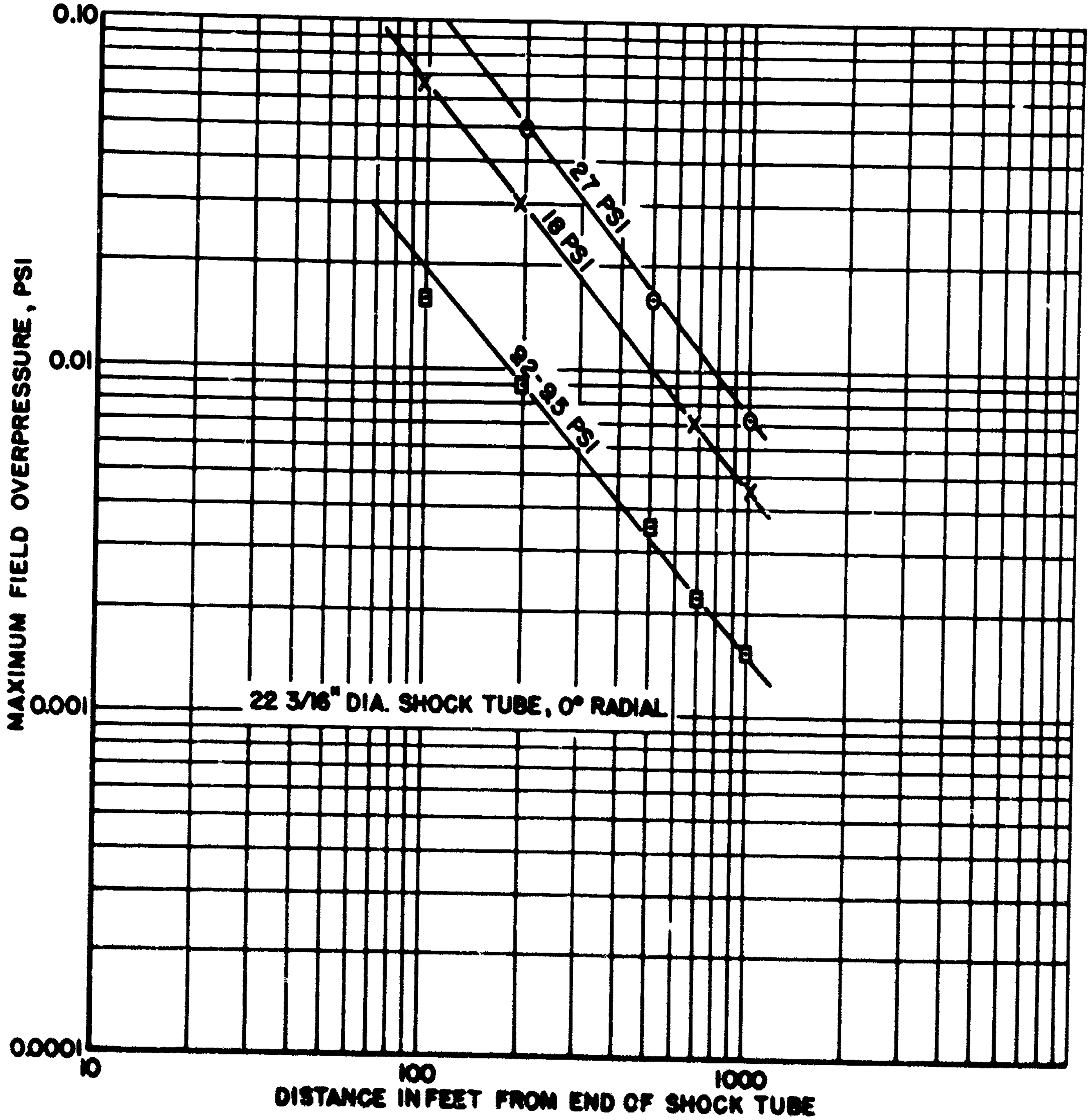



FIG. 2 MAXIMUM FIELD OVERPRESSURE VS DISTANCE FROM END OF SHOCK TUBE

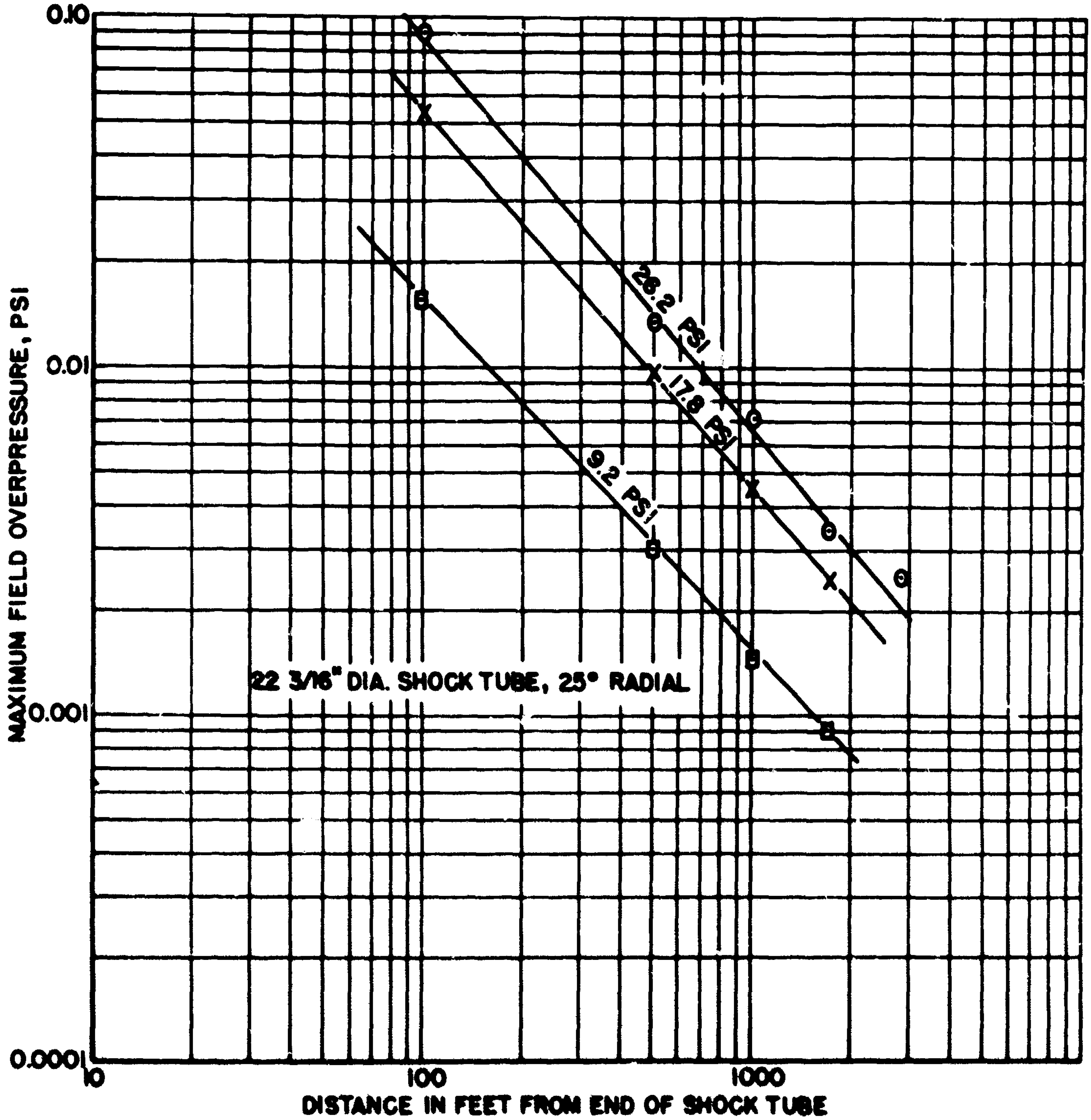



FIG. 3 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

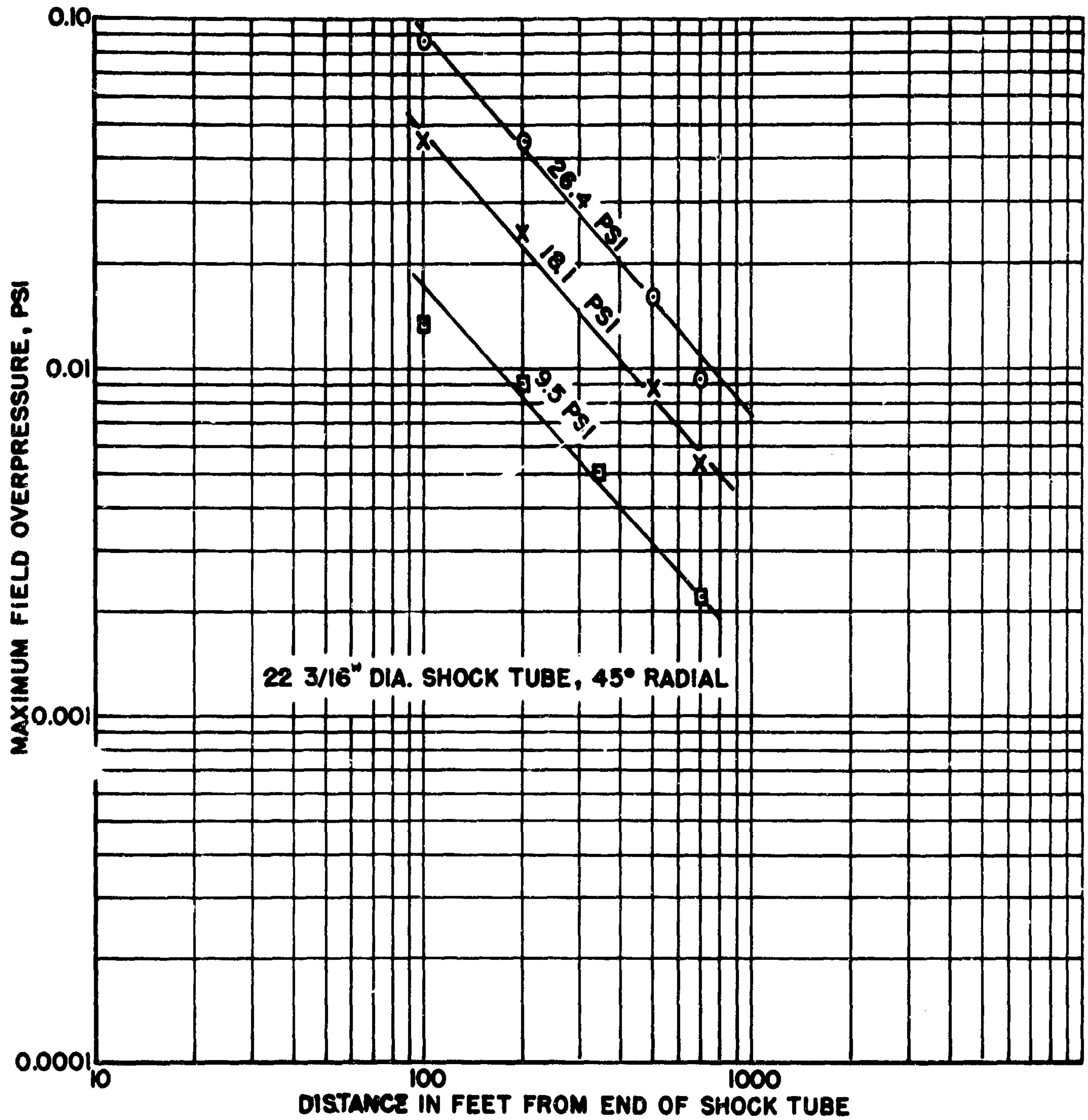



FIG. 4 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

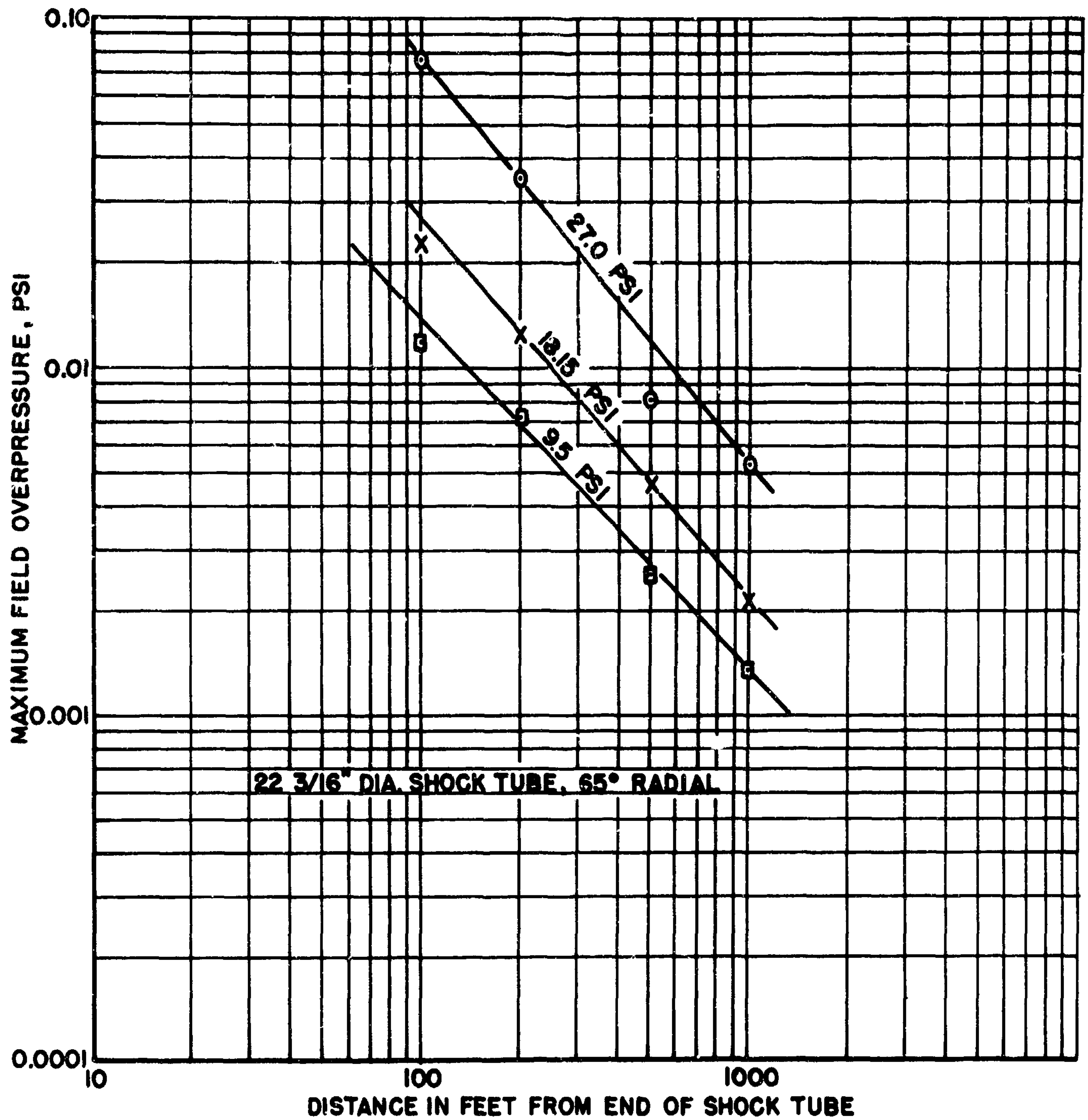



FIG. 5 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

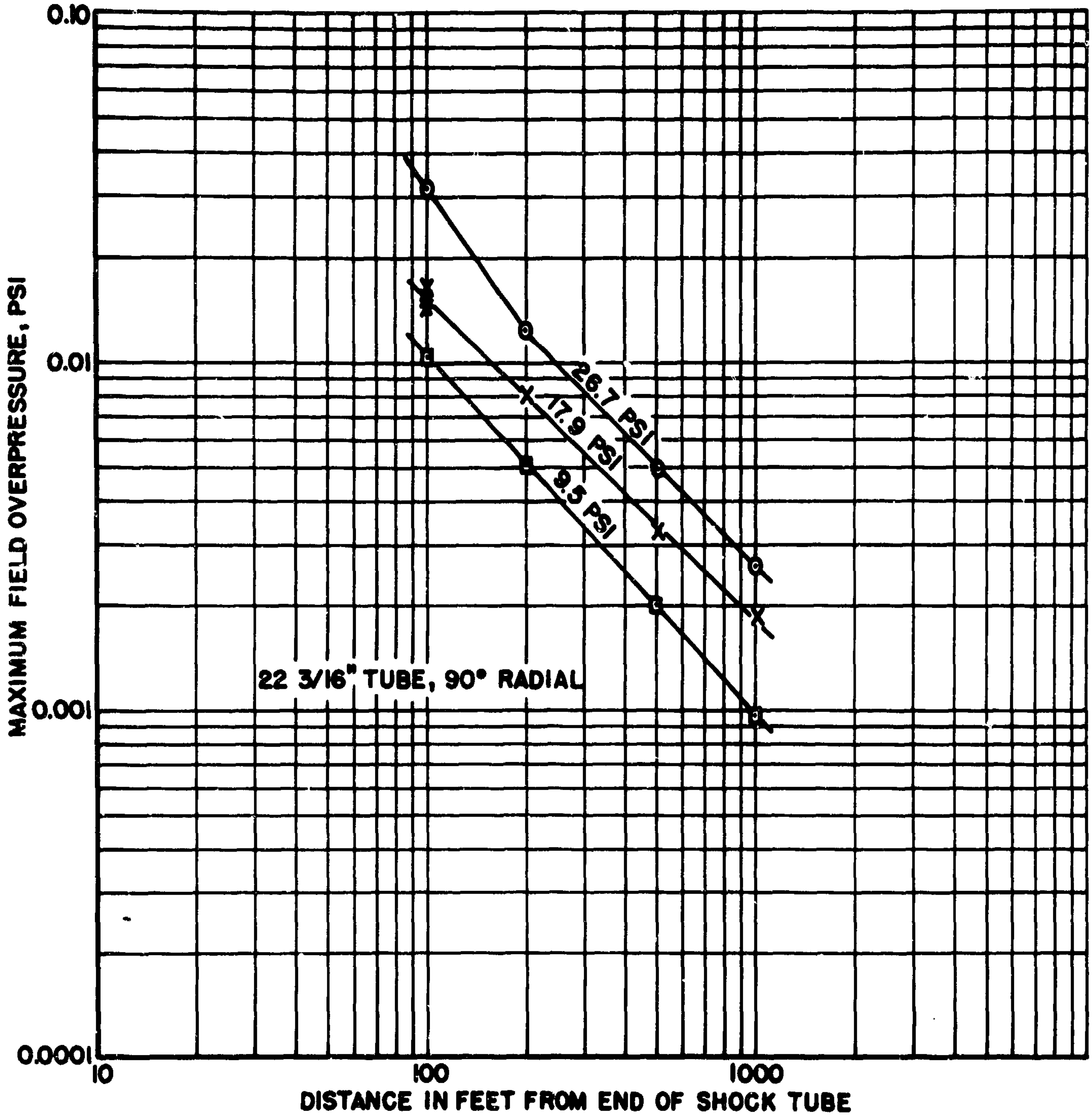



**FIG. 6 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE**

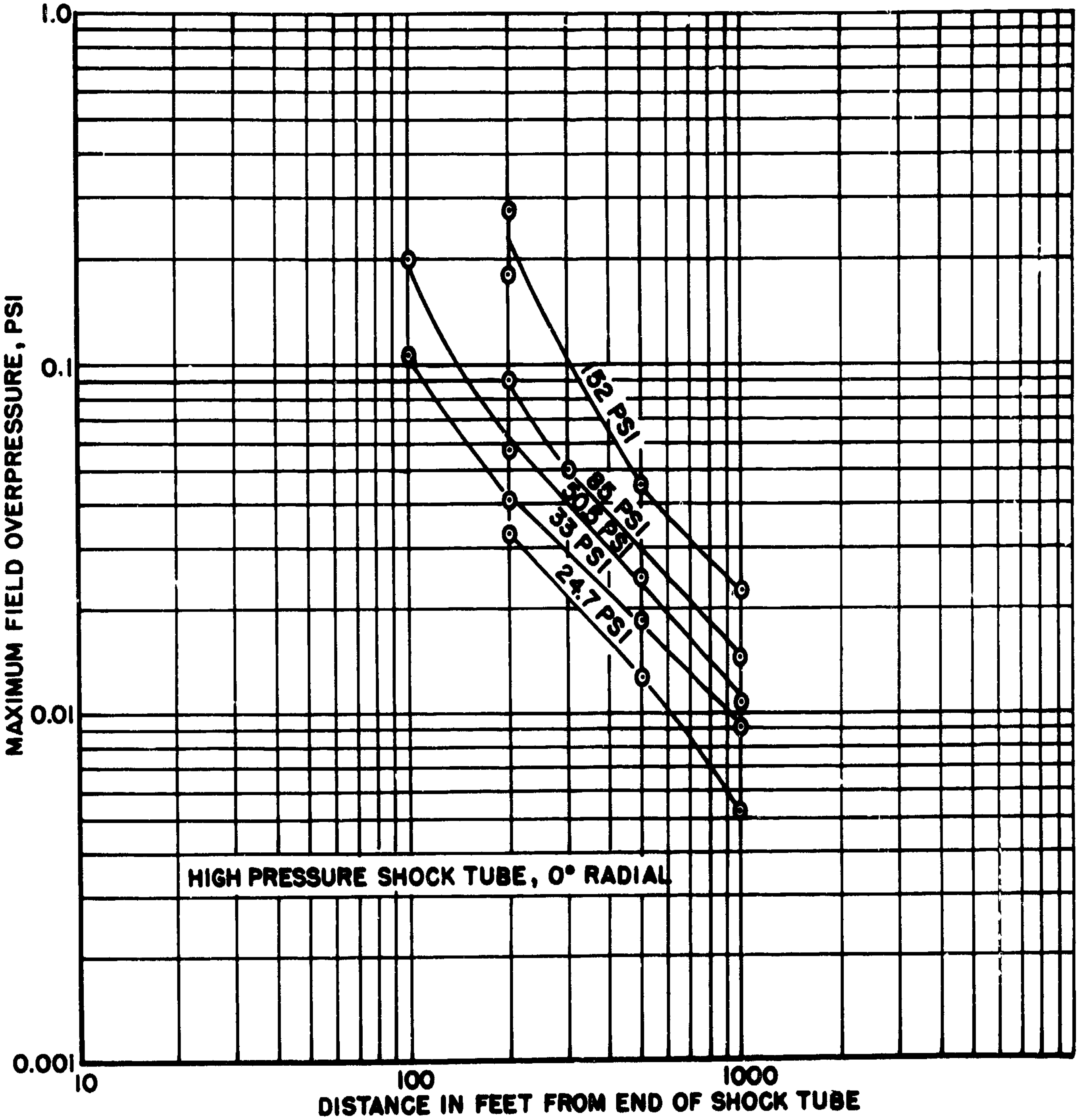



FIG. 7 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

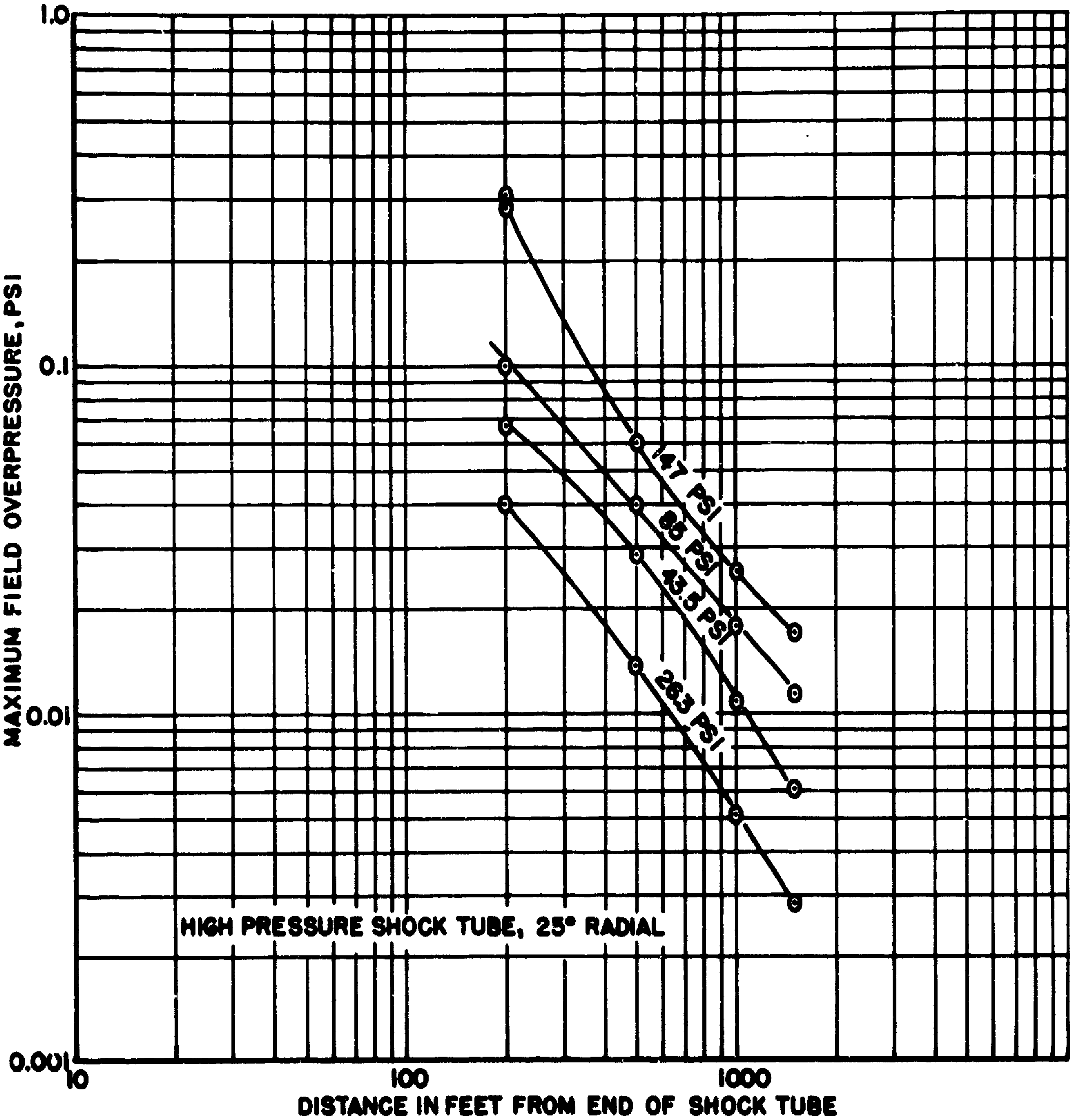



FIG. 8 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

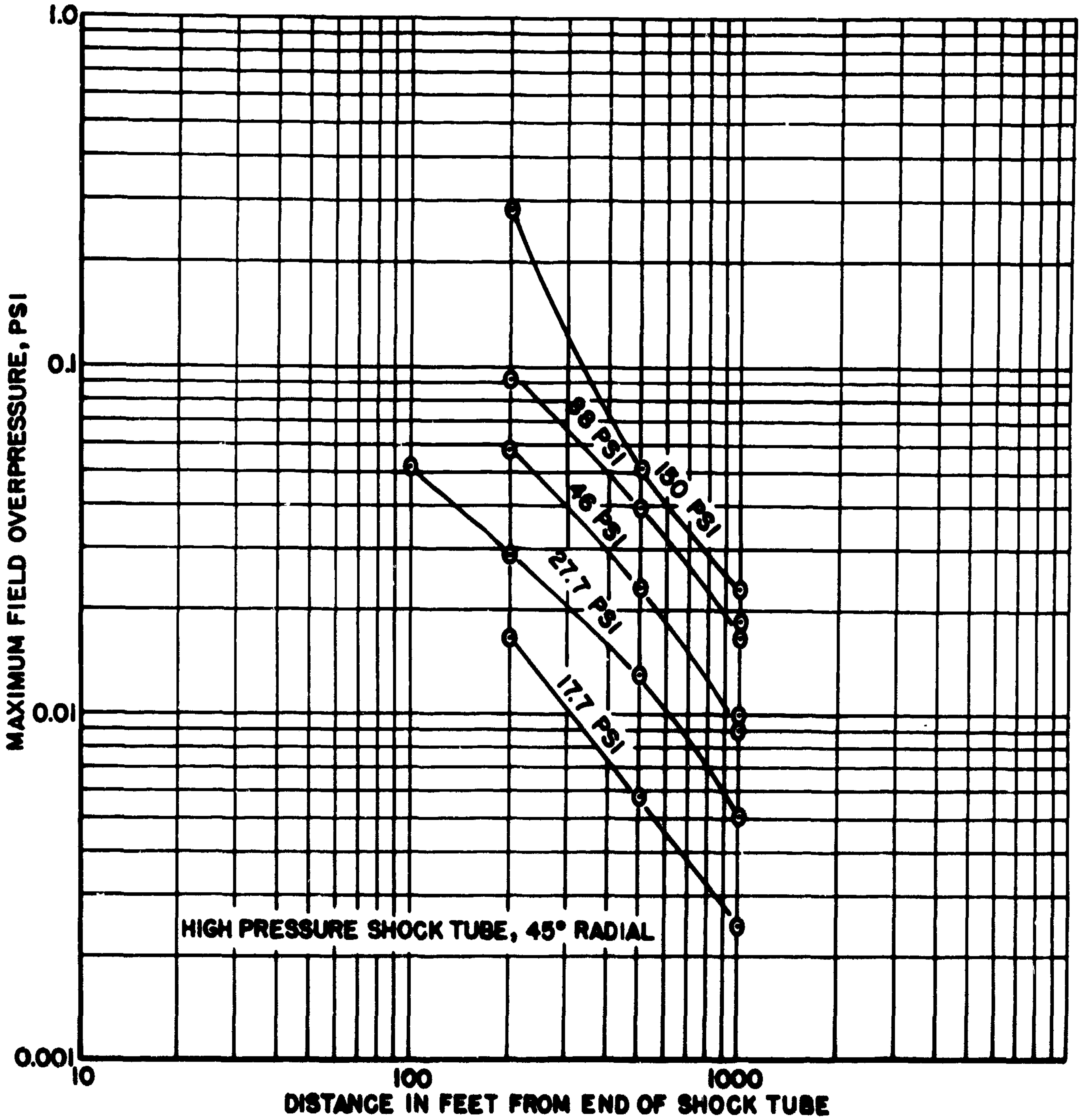



FIG. 9 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

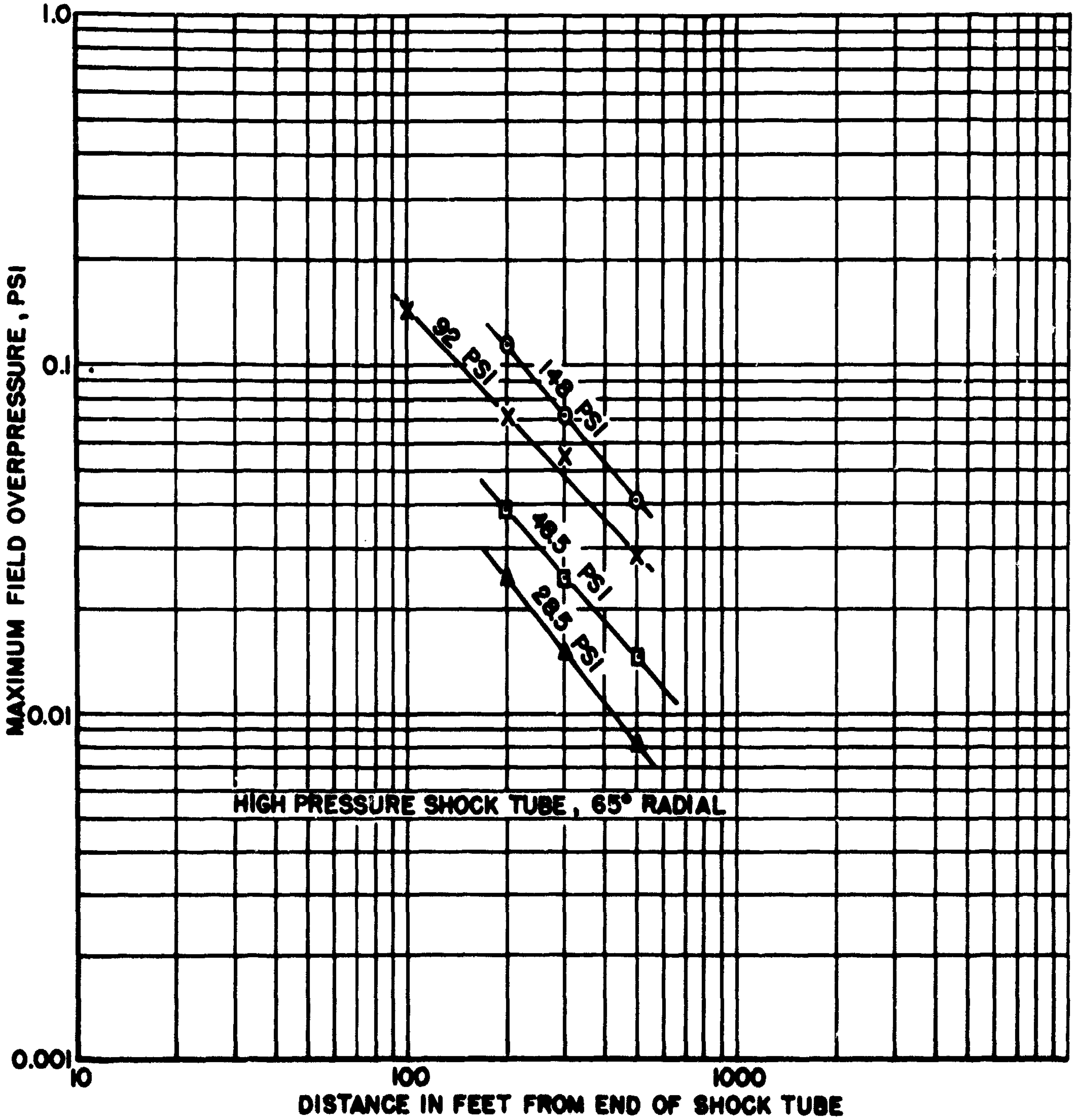



FIG. 10 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

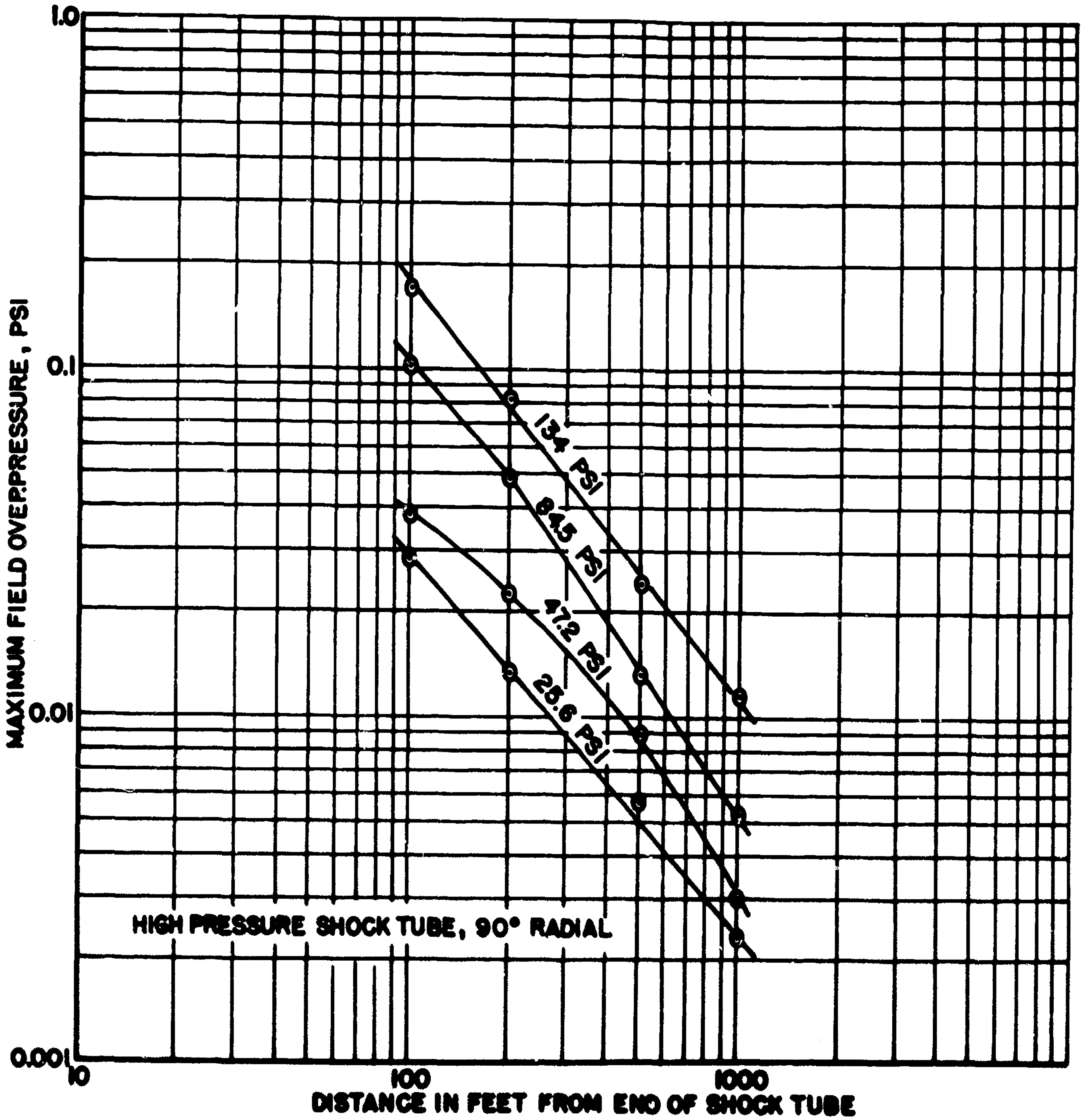



FIG. 11 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

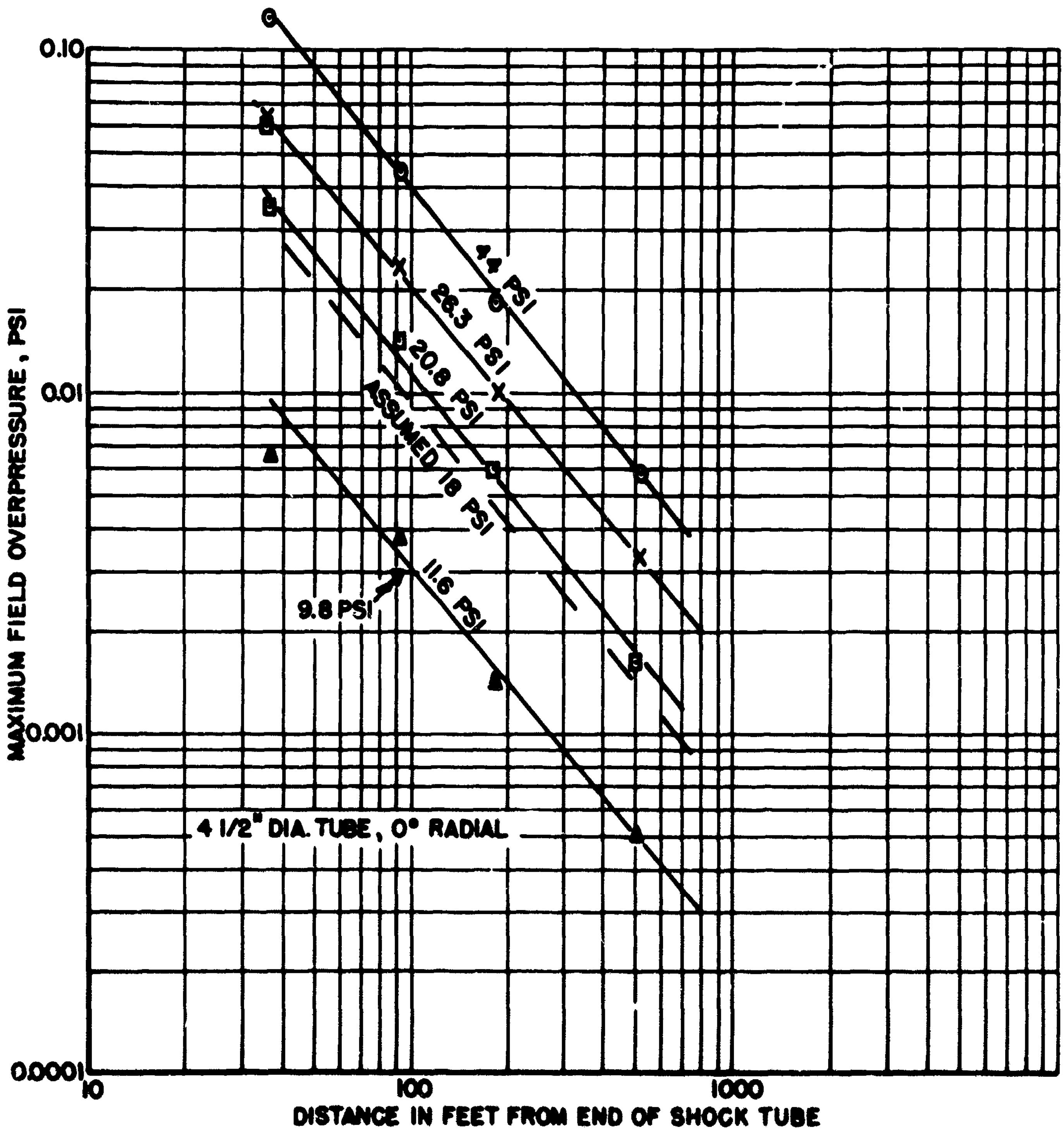



FIG. 12 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

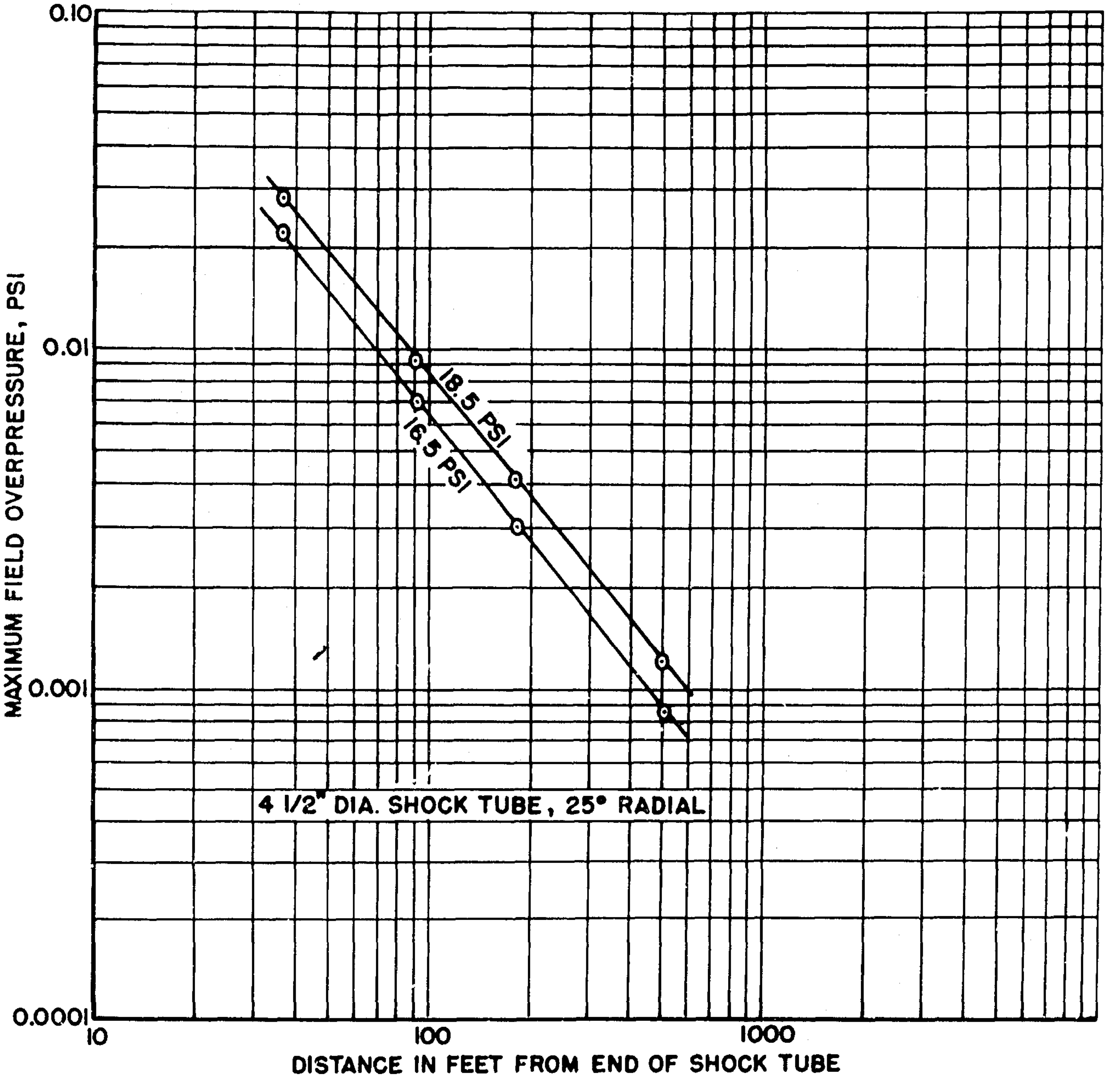



**FIG. 13 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE**

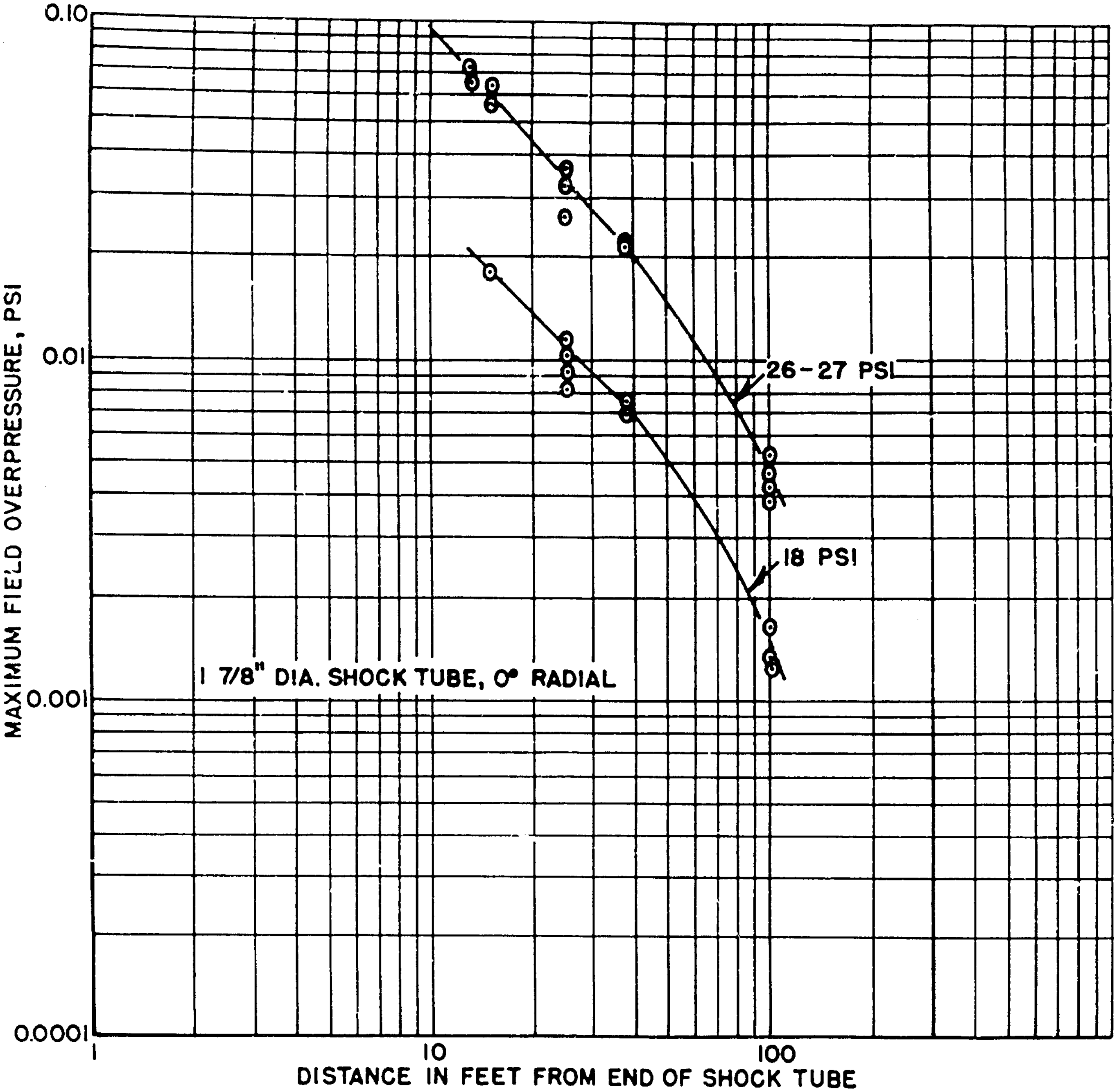



FIG. 14 MAXIMUM FIELD OVERPRESSURE Vs DISTANCE FROM END OF SHOCK TUBE

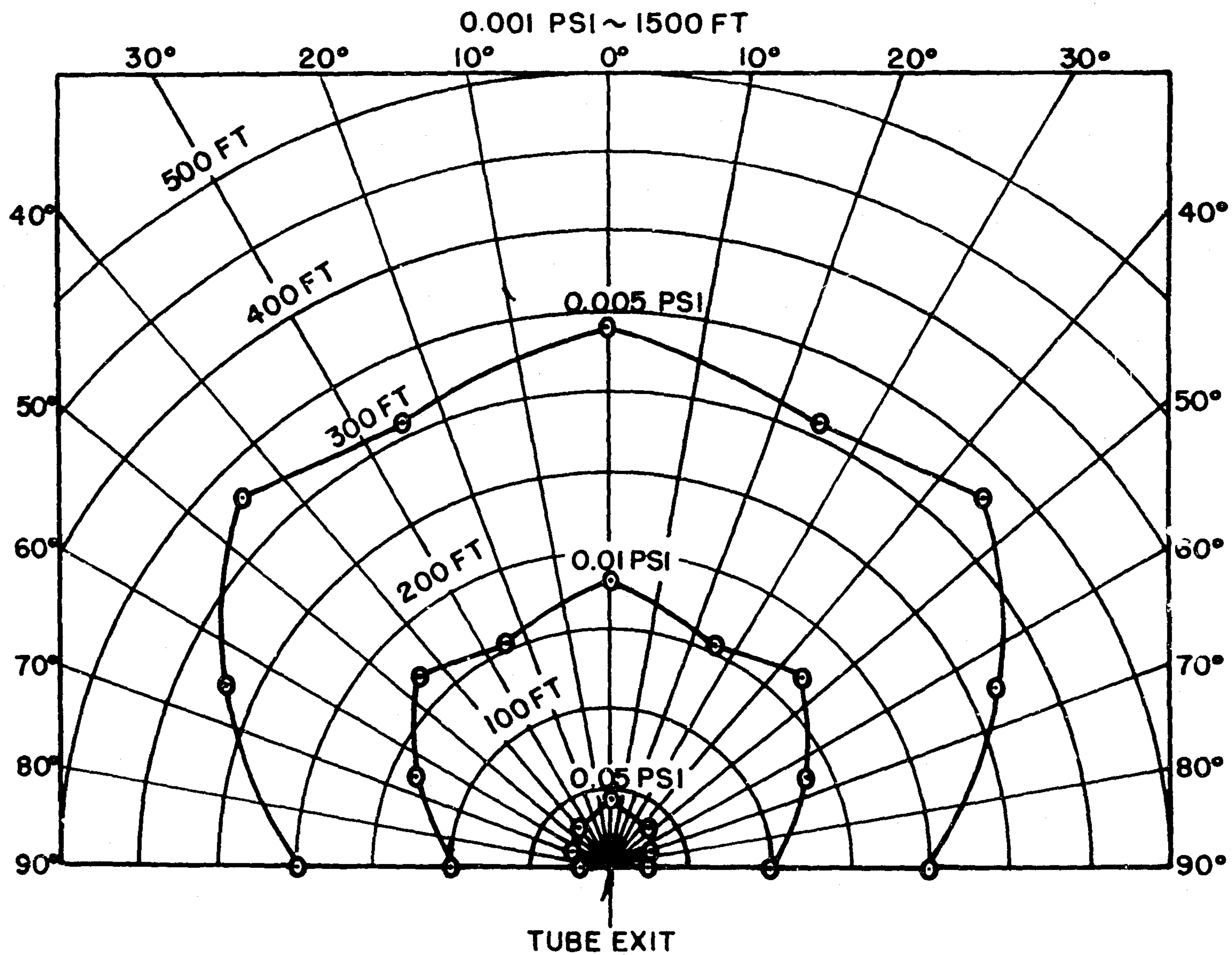



FIG. 15 CONTOURS OF EQUAL PRESSURE RESULTING FROM 9-9 1/2 PSI SHOCKS LEAVING A 22 3/16" I.D. TUBE

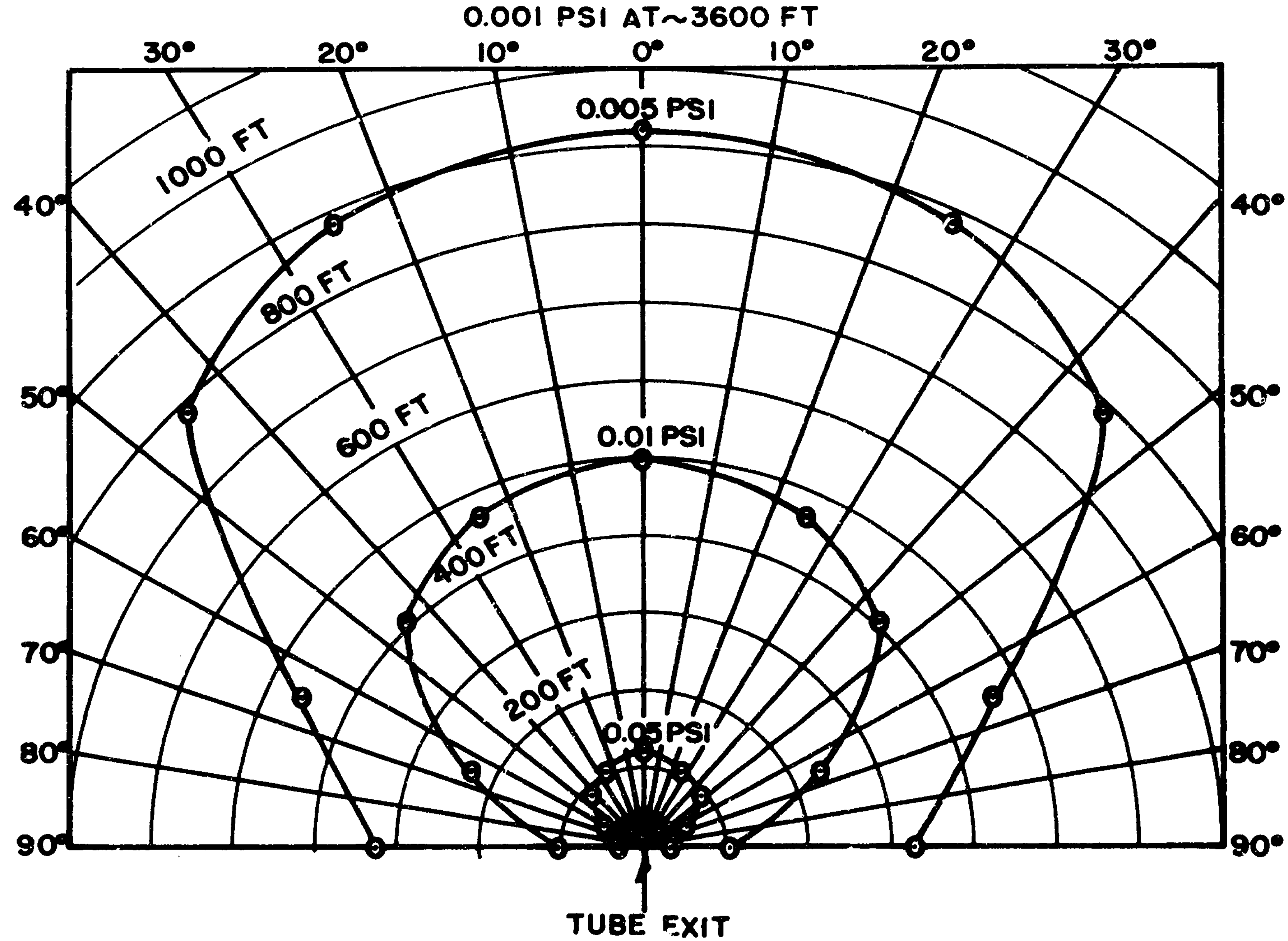



FIG. 16 CONTOURS OF EQUAL PRESSURE RESULTING FROM AN 18 PSI SHOCK LEAVING A 22 3/16" I.D. TUBE

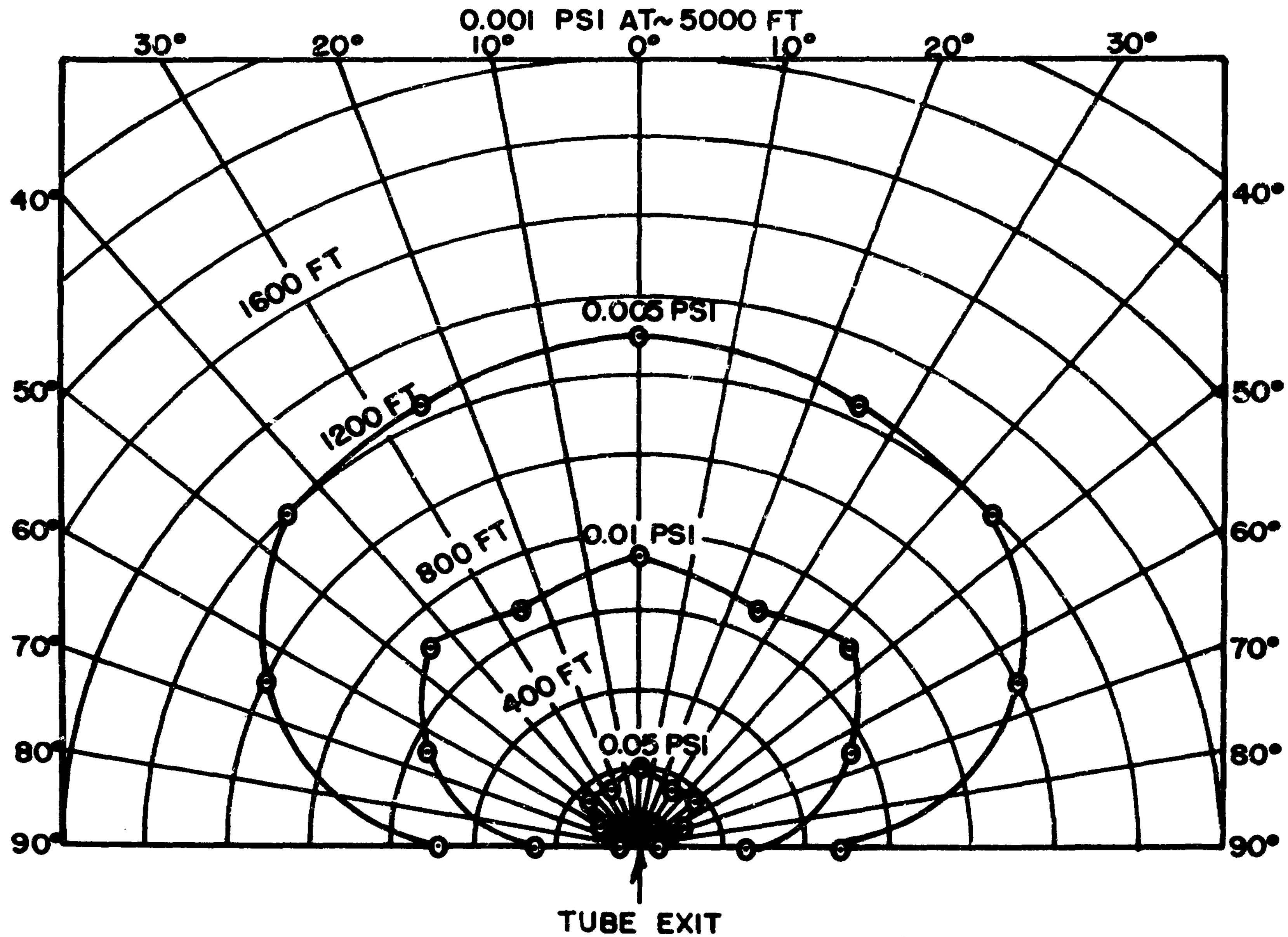



FIG. 17 CONTOURS OF EQUAL PRESSURE RESULTING FROM A 27 PSI SHOCK LEAVING A 22 3/16" I. D. TUBE

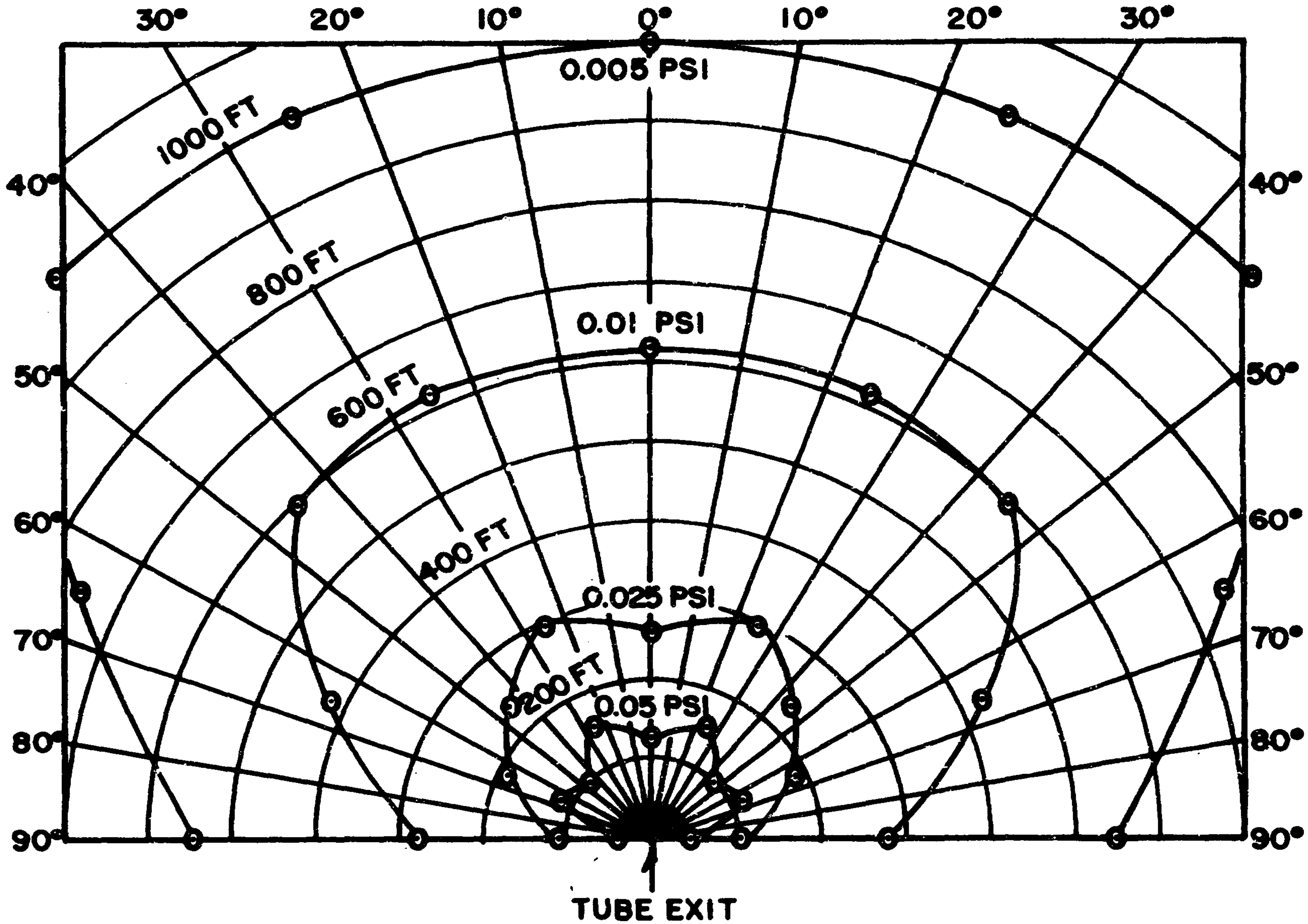



FIG. 18 CONTOURS OF EQUAL PRESSURE RESULTING FROM 25-28 PSI SHOCKS LEAVING THE HIGH PRESSURE SHOCK TUBE

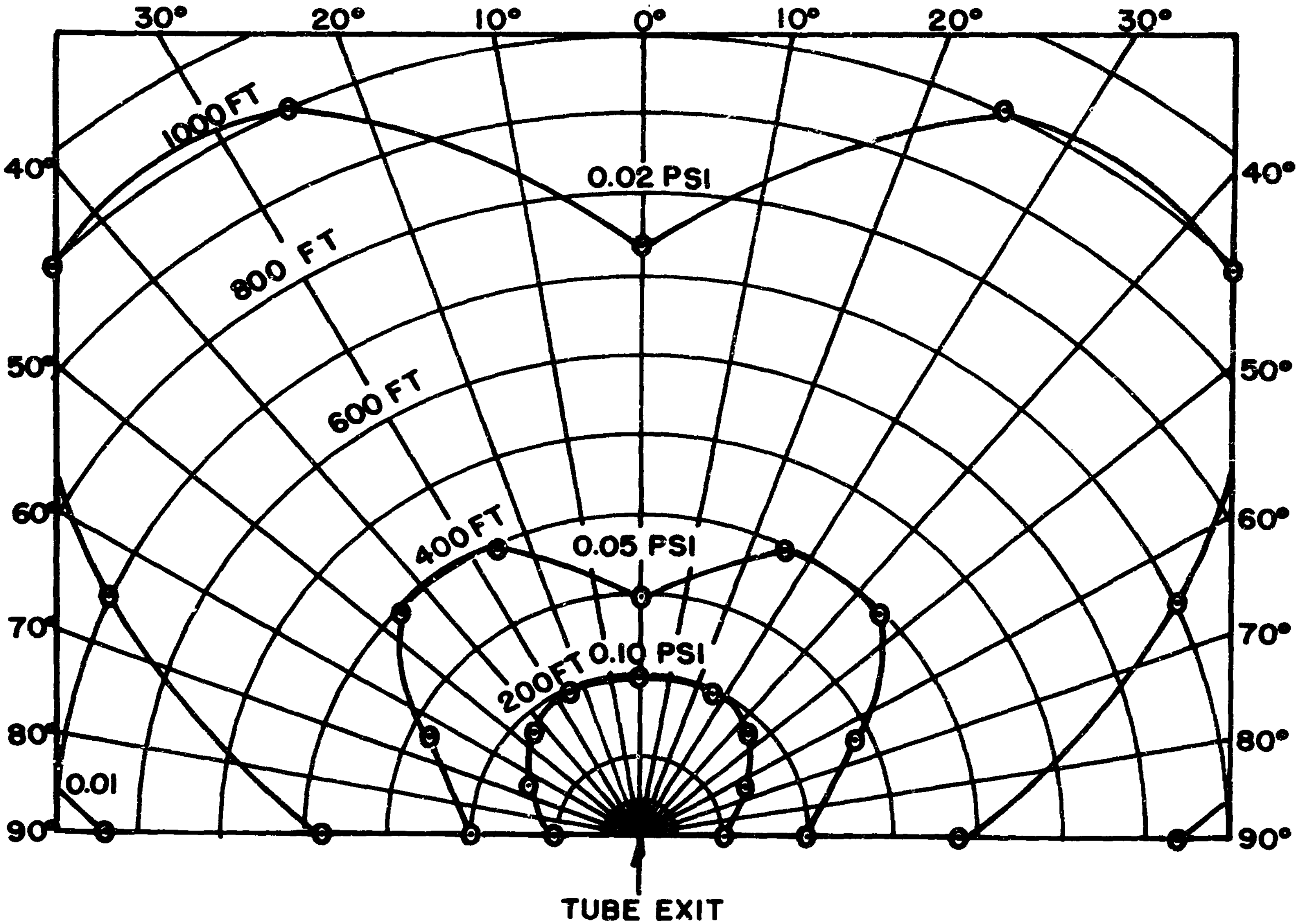



FIG. 19 CONTOURS OF EQUAL PRESSURE RESULTING FROM 85-92 PSI SHOCKS LEAVING THE HIGH PRESSURE SHOCK TUBE

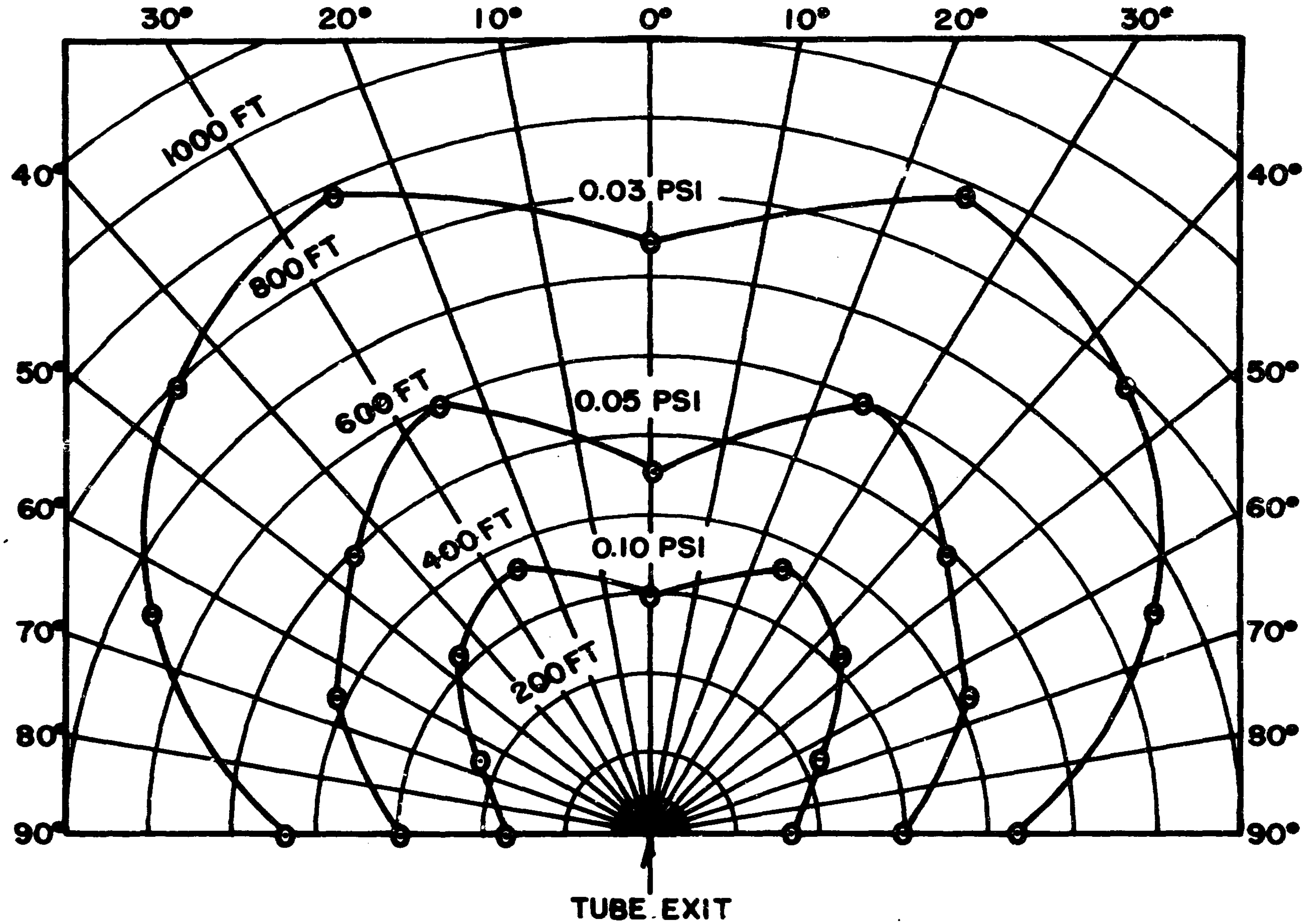



FIG. 20 CONTOURS OF EQUAL PRESSURE RESULTING FROM A 150 PSI SHOCK LEAVING THE HIGH PRESSURE SHOCK TUBE

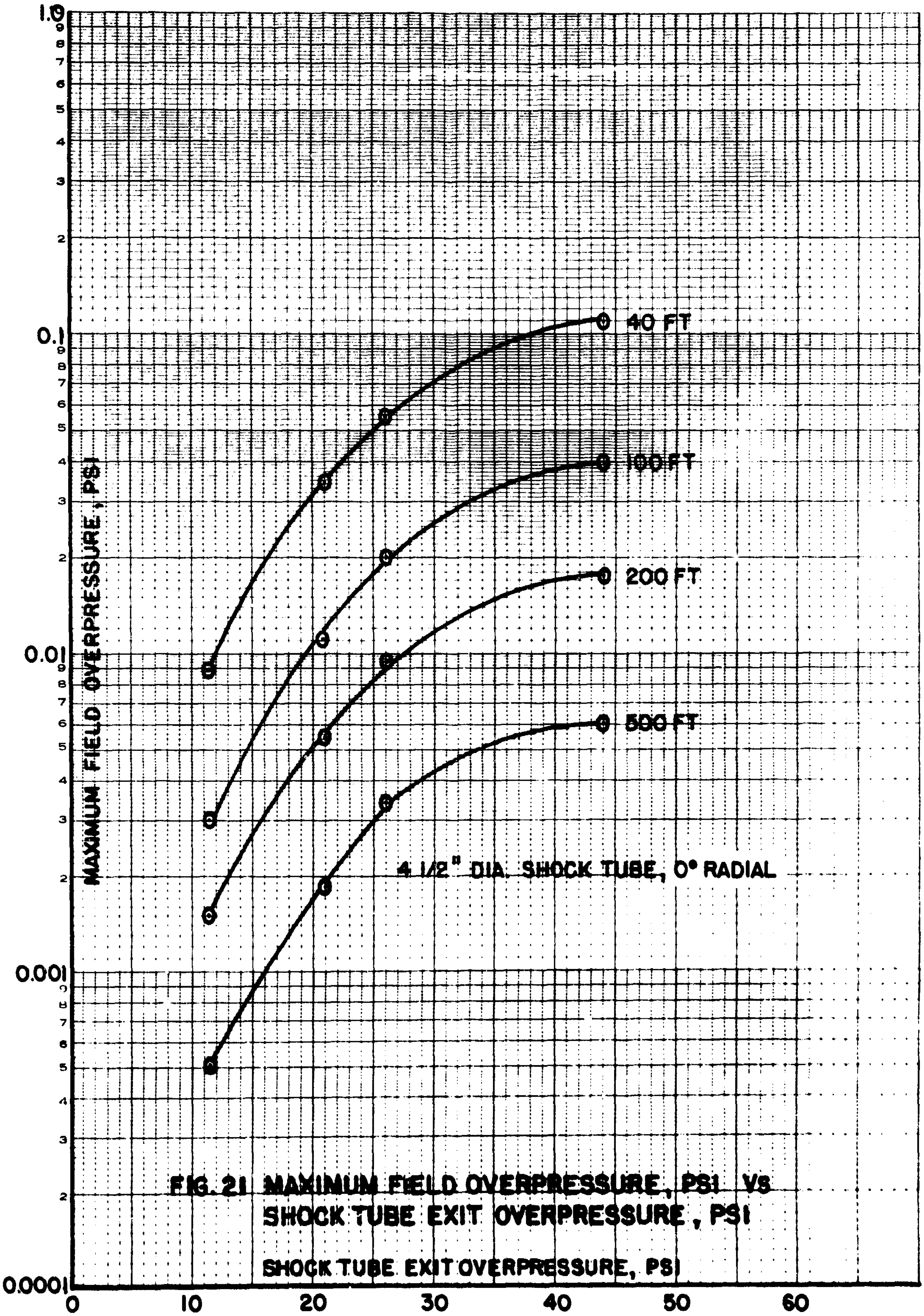



FIG. 21 MAXIMUM FIELD OVERPRESSURE, PSI VS SHOCK TUBE EXIT OVERPRESSURE, PSI

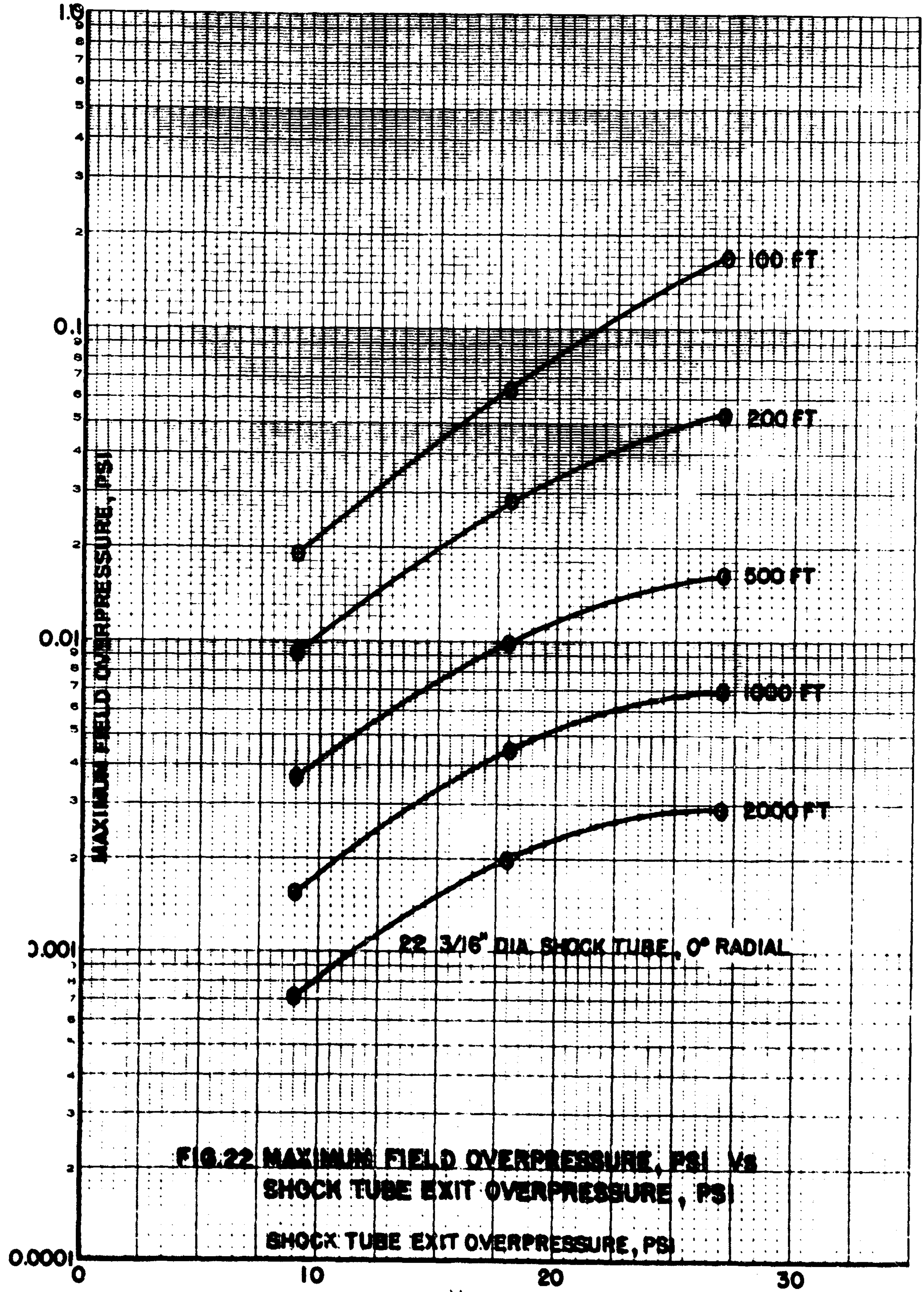
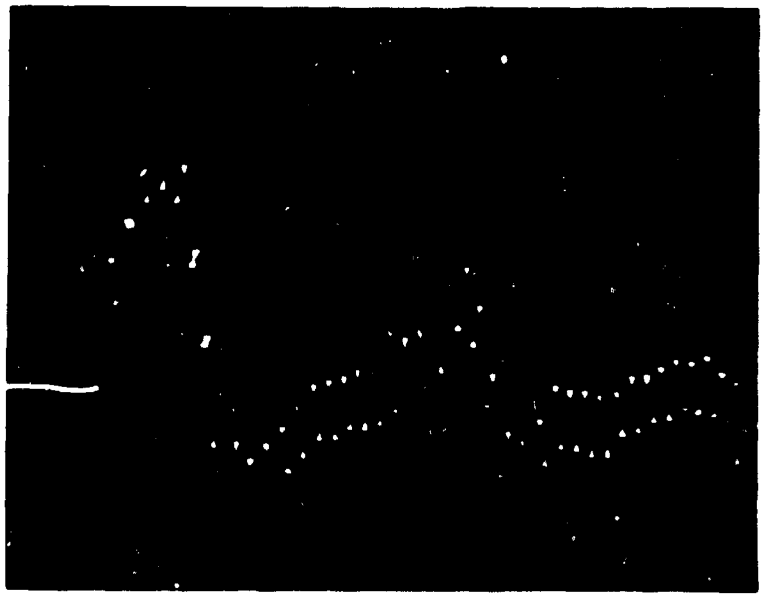


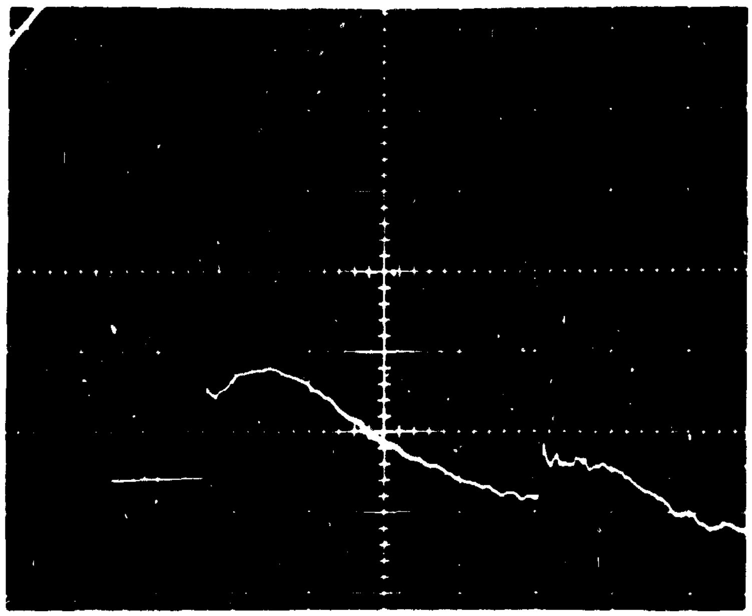
FIG.22 MAXIMUM FIELD OVERPRESSURE, PSI Vs
SHOCK TUBE EXIT OVERPRESSURE, PSI



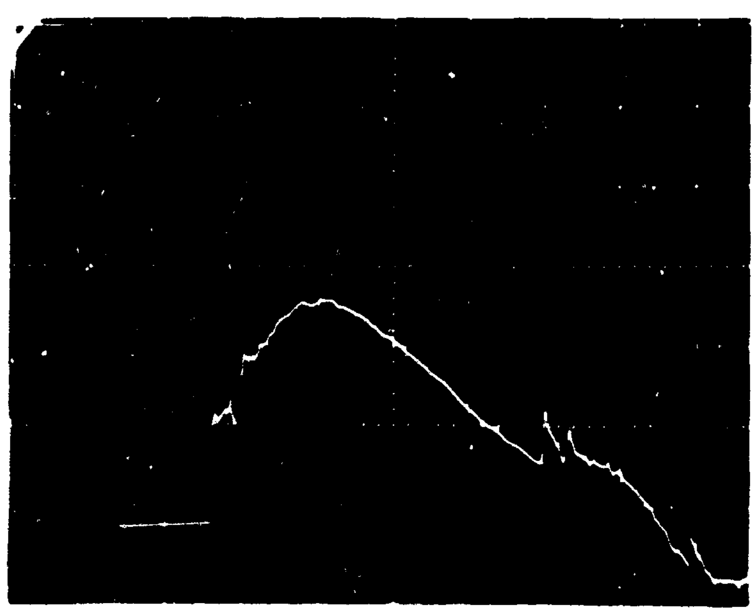
(A) 1 7/8" DIA. SHOCK TUBE
SHOCK TUBE OVERPRESSURE 26 PSI
DISTANCE FROM TUBE EXIT 13 FT
SWEEP SPEED 1 MSEC/CM (C.E.C. GAGE)

(B) 4 1/2" DIA. SHOCK TUBE
SHOCK TUBE OVERPRESSURE 27 PSI
DISTANCE FROM TUBE EXIT 35 FT.
SWEEP SPEED 1 MSEC/CM (C.E.C. GAGE)

FIG. 23 TYPICAL FREE-FIELD OVERPRESSURE Vs TIME RECORDS



(A) 22 3/16" DIA. SHOCK TUBE
SHOCK TUBE OVERPRESSURE 25 PSI
DISTANCE FROM TUBE EXIT 200 FT
SWEEP SPEED 2 MSEC/CM (PENCIL GAGE)



(B) HIGH PRESSURE SHOCK TUBE
SHOCK TUBE OVERPRESSURE 150 PSI
DISTANCE FROM TUBE EXIT 325 FT
SWEEP SPEED 2 MSEC/CM (PENCIL GAGE)

FIG. 24 TYPICAL FREE-FIELD OVERPRESSURE VS TIME RECORDS

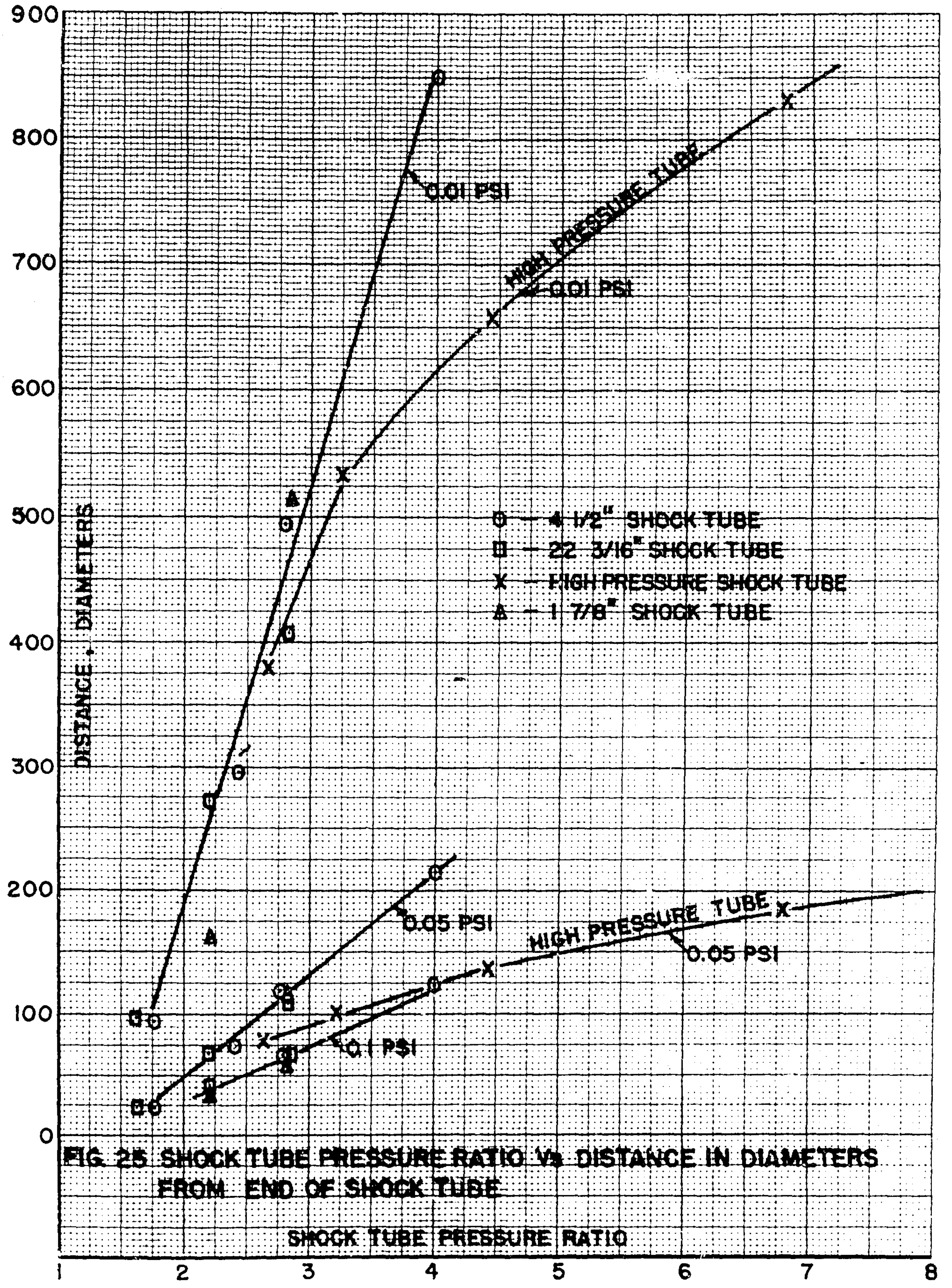



FIG. 25 SHOCK TUBE PRESSURE RATIO Vs DISTANCE IN DIAMETERS FROM END OF SHOCK TUBE

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13. ABSTRACT

The field wave overpressures and durations resulting from shock waves emerging from open-ended shock tubes have been measured. An equation has been developed from the measured data that relates the field overpressures (below 0.1 psi) resulting from a given shock tube pressure, to the tube diameter and distance from the tube exit. An equation has also been developed from the same data that relates the duration of the field wave (below 0.1 psi) to the exit areas of the tubes for a given shock tube pressure. Predictions of field overpressure and duration have been made for an eight foot diameter shock tube firing a 27 psi shock wave.

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| 14. KEY WORDS | LINK A ROLE | LINK A WT | LINK B ROLE | LINK B WT | LINK C ROLE | LINK C WT |
|---|---|---|---|---|---|---|
| Shock tube | | | | | | |
| Transmitted field overpressure | | | | | | |
| Field overpressure duration attenuation | | | | | | |

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